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APPENDICES TO HANDBOOK OF FABRIC FILTER TECHNOLOGY

VOLUME II

FABRIC FILTER SYSTEMS STUDY

Prepared by

GCA CORPORATION
GCA TECHNOLOGY DIVISION
Bedford, Massachusetts

Contract No. CPA-22-69-38

December 1970

Prepared for

DIVISION OF PROCESS CONTROL ENGINEERING
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service

FOREWORD

This document is submitted to the Department of Health, Education and Welfare, National Air Pollution Control Administration, in partial fulfillment of the requirements under Contract CPA 22-69-38. The principal technical objectives under the contract were: (1) to evaluate the status of engineering technology currently available to the researcher, manufacturer and user of fabric filter systems; (2) investigate the current practices in the application of fabric filtration; (3) investigate major air pollution control areas which could be amenable to control by fabric filtration; (4) make a critical review and engineering evaluation of the major types of fabric filter devices currently available in order to assess the strength and weakness of each type of device; (5) prepare a comprehensive report containing the information collected in the task areas cited above; and (6) develop five-year research and development programs specifying the research and development efforts required to fill the stated technical gaps. The results of the contract efforts are presented in the following four volumes:

Volume I - Handbook of Fabric Filter Technology
Volume II - Appendices to Handbook of Fabric Filter Technology
Volume III - Bibliography of Fabric Filter Systems Study
Volume IV - Final Report of Fabric Filter Systems Study

The following professional staff members of the GCA Technology Division contributed to the study and preparation of this report: Dr. Charles E. Billings, Mr. Richard Dennis, Dr. Leonard M. Seale, and Dr. John Wilder. The results of the contract efforts, partially presented in this document, covered the period from January 1969 to January 1971.

Mr. Dale Harmon of the Process Control Engineering Division, National Air Pollution Control Administration, served as the Contract Project Officer.

areas covered by the appendices

Some of the ^ contained in the report include:

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APPENDIX 1.1

TABULATION OF THE EARLY HISTORY OF THE USE OF FABRICS FOR DUST AND FUME FILTRATION, AND EARLY CONTRIBUTIONS TO FILTRATION THEORY

EARLY HISTORY OF FILTRATION FOR HEALTH PROTECTION

Date	Author	Remarks
ca 50 AD	Pliny(R)	Recognition of problem with red oxide of lead (minium) pigment in refiners; loose bladders over face to prevent inhalation.
ca 50 AD	Dioscorides (Gr)	Risks with minium refining, and dangers of mining.
ca 150 AD	Pollux(Egy)	Recognized problem of dust in mines, and used sack (woven) overhead, tied around neck, with window bladder for vision. Sack was utilized as air filter.
1500 AD	L. daVinci	Wet cloth covering mouth and nose.
1556	Agricola	Mentions asbestos cloth (ca. 700BC); illustrates balloon flues for ZnO.
1656	Stockhausen	Firesetting (in situ calcining) to aid in breaking rock, protect nose and mouth with rags (to 200 B.C.).
1700	Ramazzini	Glass masks. Gypsum and lime workers cover nose and mouth. Tobacco workers cover nose and mouth. Bakers and millers separate flour from bran with sieves: flour inhalation, cover mouth with linen bandage.
1613	Pignoria	Had bakers cover mouth with towel.
1814	Brise-Fradin	Iron, filter box, filled with cotton mounted on chest with tubes to remove mercury.
1811	Thos. Wood	Wet cloth filter for grinding dust.
1813	Geo. Prior	Bellows to blow away dust.
1822	Thos. Abraham	Respirator, magnetic guard, with 3 layers muslin over mouth and nose in grinding, also wet cloths to collect impinging dust, isolation of dusty operations.

1828	Roberts	Woolen cloth plus moist sponge for smoke mask.
1849	Haslett	Woolen fabric for dust respirator.
1899	Federath	Respirators unsatisfactory, use cloth over mouth and nose.
1837-1859	Jul. Jeffrys	Medical respirator for mines.
1854	Stenhouse	Use of charcoal for filtration.
1855	F. Watson	Charcoal filters in Guildhall ventilation.
1860-70	Pasteur	Germ theory of disease, heated Pt. gauge, airborne infection described.
1866	Shaw & Tyndall	Charcoal, lime (CO_2) filter
1868	John Tyndall	First quantitative investigation of fibrous filter efficiency -- "respirator of cotton-wool," using light scatter in Tyndall beam, strong coverging.
1871		Laboratory glass wool suggested as filter, Oakum.
1885	Prince	Hospital operating room bacteria count $6300/cm^3$, filtration used to remove.

EARLY CONTRIBUTIONS TO THE THEORY OF FILTRATION

1827	Robert Brown	Brownian Motion
1905	Einstein	Diffusion constant for aerosols and displacement by diffusion f(t).
1921	Freundlich	Filter penetration illustrating maximum penetration at approximately 0.3μm.
1926	Katz, et. al. Bu. Mines.	Efficiency approximately e^n where n is no. of layers.
1930	Hansen	Resin filter, electrets (permanent dipole).

1931	Albrecht	Inertial deposition on cylinders, ideal fluid.
1931	Sell	Inertail deposition on cylinders, ideal fluid.
1932	Whytlaw-Gray	Inelastic collision of small particles demonstrated.
1936	Kaufmann	Direct interception, attempt at unified theory.
1938	Hill	Carding resin-wool filters.

From 1940 onward, there are a large number of publications and patents on filter materials, additives, configurations, fabrication, and testing, many of which are considered in the Handbook.

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APPENDIX 1.2

COPY OF
JONES PATENT

hausting apparatus, and at the same time not to prevent the escape of the air and accompanying gases, which will be by the most gentle exhalation through the extended surfaces formed by the sides of the receiving bag or chamber, or otherwise the desired products will escape at the same time and be lost. It is evident, therefore, that a single strainer of moderate size will be ineffective and unable to accomplish the collection of such rare substances to any useful or desirable extent, and that the extended surfaces of my receiving bag or chamber, whose sides are composed entirely or principally of the porous cloth, will be adequate thereto. A bag about eight feet in diameter and seventy feet long has been used for the collection of the white oxide of zinc from sixty small retorts; but if made larger, better results will be attained; and, if deemed advisable, the diameter of the bag may be lessened, while its length should be increased in proportion; or several bags may be used instead of a single one; and so, also, in respect to a chamber composed of porous sides of cloth, should it be used in preference to a bag.

It is evident that a square or oblong chamber may be used instead of a bag, the principal portions of the top or sides or bottom part of which may be formed of the straining-cloth, as above described. An air-tight chamber may also be used with a straining-bag adapted to its end and passing into the interior of the chamber, the end of the bag being in communication with the main or tubes communicating with the retorts or ovens; and on applying the exhausting apparatus at the other end of the chamber the same object may be accomplished. Besides collecting the products of zinc, it is evident that these collecting bags or chambers may be used for other similar useful purposes.

I am aware that lamp-black has been collected by causing it to deposit on the inner surface of a series of canvas bags by causing the products of the combustion to pass through a series of such bags, the upper end of the last of the series being open for inducing a current; but this cannot be successfully employed for the collection of the volatile products of the distillation or oxidation of zinc and other volatile metals, for the reason that there is a great waste by the escape at the open end of the series; and I am also aware that lamp-black has been collected on the inner surface of a hood made of porous cloth covering a vessel or receiver, the gases escaping through the meshes or pores of the cloth and depositing the lamp-black on the inner surface; but this will not answer a practical purpose for the collection of the volatile products of the distillation or oxidation of zinc and other volatile metals, because the cloth hood so far impedes the draft induced by rarefaction that the collection will not be formed on the surface of the cloth; and if the pores or meshes of the cloth be made sufficiently large to induce the required draft, then the metallic fumes will escape and be wasted; and I am also aware that it has been tried to effect the separation of the air and other foreign gases from the gaseous products of the distillation of zinc by drawing or forcing the air and foreign gases through the pores or meshes of screens placed in the collecting-chamber or the flue; but this has been found to be impracticable, for the reason that the amount of surface presented by such screen or screens is insufficient for the separation, unless the collecting-chamber be made of so great a capacity as to occupy an amount of room too great for practical purposes. I do not therefore wish to be understood as making claim, broadly, to the use of a screen or screens with forced currents for the separation of air and other foreign gases from the gaseous products of distillation, nor do I claim, separately, making the collecting-chambers of woven cloth when this is not used in combination with the means of producing a forced current; but

What I claim as my invention, and desire to secure by Letters Patent, is—

The use of a porous or fibrous bag or receiving-chamber with porous sides or bottom, or an air-tight chamber with a straining or porous bag adapted to the inside thereof, and used in connection either with a blowing or exhausting apparatus, so that the products of the distillation and oxigenation of zinc or other volatile metals may be separated from the accompanying air and gases, which latter will be forced or otherwise drawn through the pores of the cloth bag or chamber and escape into the atmosphere.

S. T. JONES.

Witnesses:

CHARLES N. BAMBURGH,
F. C. HOLBROOK.

APPENDIX 1.3

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS

(1950, 1954, 1961; for 1969 Listing
See Appendix 3.1)

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PRINCIPAL U.S. MANUFACTURERS AND TYPES OF COLLECTORS - 1950[**]

Name of Manufacturer	Address	Trade Name Of Unit	Characteristics*	Method of Cleaning
American Wheelabrator and Equipment Company	Mishawaka, Ind.	Dustube Dust Collectors	Vertical cloth dust tubes Standard Unit Capacities -270 to 47000 c.f.m.	Mechanical shaking at top of dust tubes
Blaw-Knox	Pittsburgh, Pa.	Blaw-Knox Framed Bag	Framed Bags-collection on outside of bag	Bag frames rapped by beaters vibrated by motor drive
Day Company	Minneapolis 13, Minn.	Autoclean Dust Filter	Vertical cloth dust tubes with traverse ring Standard Capacities-664 to 16128 c.f.m.	Reverse air jet operating through [illegible] ring
Dracco Corporation	Cleveland 5, Ohio	Multibag Filter and Automatic Filters	Vertical cloth dust tubes Cloth areas 800 to 16000 square feet	Mechanical shaking at top of dust tubes
Northern Blower Company	Cleveland 2, Ohio	Norblo Standard Bag Type and Automatic Bag Type	Vertical dust tubes Standard-1872 to 33726 c.f.m. Automatic-2880 to 34560 c.f.m.	Mechanical shaking at top of dust tubes
Pangborn Corporation	Hagerstown, Md.	"CH" Dust Collector	Cloth covered wire mesh screen frame. Collection on outside of bag. 1080 to 29900 square feet	Mechanical rapping of frames with screen beaters
Pulverizing Machinery Company	Summit, New Jersey	The Mikro-Collector	Single vertical felt bag units with traverse ring. Standard sizes 500 c.f.m. up	Reverse air jet operating through traverse ring
Richmond Manufacturing Company	Lockport, New York	Niagara Dust Collector. Empire Dust Collector	Cloth tubes arranged in circle to revolve. Max. size 1500 sq. feet of cloth	Automatically cleaned by reverse air and rapping
W.W. Sly Manufacturing Company	Cleveland, Ohio	Sly Dust Filter	Cloth bags on screen frame. Dust collects on outside of bag. Capacities -1122 to 41888 c.f.m.	Bags rapped mechanically at top
Turner and Haws Engineering Company	W. Roxbury 23, Mass.	Aeroturn	Single and multiple vertical felt bags with traverse ring. All sizes custom built	Reverse air jet operating through traverse ring

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[*] Collection on inside of bag or tube unless otherwise noted.

[**] From Silverman, L., Filtration Through Porous Materials, Ind. Hygiene Q. 11:11 (March 1950).

PRINCIPAL U.S. MANUFACTURERS AND TYPES OF CLOTH FILTER DUST AND FUME COLLECTORS - 1954*

Name and Address of Manufacturer	Trade Name of Unit	Characteristics*	Method of Cleaning
American Air Filter Company, Inc. Louisville, Kentucky	Amerjet	Vertical cloth dust tubes with traverse ring, standard sizes 123 to 1198 sq.ft.	Reverse-air jet operating through traverse ring.
American Wheelabrator and Equipment Company, Mishawaka, Indiana	Dustube Dust Collector	Vertical cloth dust tubes, standard capacities 270 to 47000 cfm.	Mechanical shaking at top of dust tubes.
Blaw-Knox Pittsburgh, Pennsylvania	Blaw-Knox Framed Bag	Framed bags**, standard sizes 560 to 30080 sq.ft.	Bag frames rapped by beaters vibrated by motor drive.
Day Company Minneapolis, Minnesota	Autoclean Dust Filter	Vertical cloth dust tubes with traverse ring, standard sizes 51 to 97.6 sq.ft.	Reverse-air jet operating through traverse ring.
Dracco Corporation Cleveland, Ohio	Multibag Filter and Automatic Filter	Vertical cloth dust tubes, standard sizes 800 to 16000 sq.ft.	Mechanical shaking at top of dust tubes. Back flow air cleaning supplied in Automatic type.
Ducon Company Mineola, New York	"UFA" Unit Dust Collectors and Uniflow Backwash Dust Collectors	Vertical cloth dust tubes, standard sizes 50 to 2000 sq.ft. Uniflow tubes open at both ends.	UFA: Shaking top of tubes with simultaneous back flow air; Uniflow: Alternating pulses of back flow and primary air.
G. A. Kleissler Company Newark, New Jersey	----	Vertical cloth dust tubes, standard sizes 101 to 8240 sq.ft.	Mechanical shaking at top of dust tubes.
Lamson Corporation Syracuse, New York	Exhaust	Vertical cloth dust tubes, standard sizes 34 to 534 sq.ft. for central vacuum cleaning systems.	Manual shaking at top of dust tubes.
The MacLeod Company Cincinnati, Ohio	MacLeod Dust Collector	Cloth tube and screen** types, standard capacities 500 to 40000 cfm.	Mechanical shaking of tube type, mechanical rapping of screen type.
Northern Blower Company Cleveland, Ohio	Norblo Standard Bag Type and Automatic Bag Type	Vertical cloth dust tubes, capacities: standard 1672 to 33726 cfm; automatic 2660 to 34560 cfm.	Mechanical shaking at top of dust tubes.
Pangborn Corporation Hagerstown, Maryland	"CH" Dust Collector Self-Cleaning Dust Collector	Cloth covered wire mesh screen frames**, standard sizes 1060 to 29800 sq.ft.	Mechanical rapping of frames with screen beaters. Back flow air cleaning supplied in self cleaning type.
Pulverizing Machinery Company Summit, New Jersey	Mikro-Collector	Vertical felt bag units with traverse rings, standard capacities 500 cfm up.	Reverse-air jet operating through traverse ring.
Richmond Manufacturing Company Lockport, New York	Niagara Dust Collector Empire Dust Collector	Cloth tubes arranged in circle to revolve**, maximum size 1500 sq.ft.	Automatically cleaned by backflow air and rapping.
Ruemelin Manufacturing Company Milwaukee, Wisconsin	Tubular Type Cloth Dust Filter	Vertical cloth dust tubes, standard sizes 53 to 9155 sq.ft.	Mechanical shaking of top of dust tubes.
Safety Car Heating and Lighting Co., Inc., Entoleter Division, New Haven, Connecticut	Steam Suction Filter	Vertical cloth dust tubes, standard capacities 1200 to 13200 cfm, eight tubes per compartment.	Tubes in each compartment lifted and dropped with simultaneous back flow air.
W. W. Sly Manufacturing Company Cleveland, Ohio	Sly Dust Filter Sly Dynaclone	Cloth bags on screen frames**, standard capacities 1122 to 41888 cfm.	Bags rapped mechanically at top. Back flow air cleaning supplied in Dynaclone type.
Sterling Blower Company Hartford, Connecticut	Sterling "Type R" Dust Collecting Unit	Vertical cloth dust tubes, standard sizes 111 to 552 sq.ft.	Bags rapped at bottom.
Torit Manufacturing Company St. Paul, Minnesota	Torit Dust Collector	Vertical cloth envelopes**, standard sizes 30 to 300 sq.ft., for unit type dust control.	Manual shaking at bottom of envelopes.
Turner and Haws Engineering Company West Roxbury, Massachusetts	Aeroturn Spiraklean	Vertical felt dust tubes with traverse rings. Vertical cloth tubes with internal rotating spiral. Rotary arm reverse-jet unit also available.	Reverse-air jet operating through traverse ring. Interior wiping by spiral scraper.
U.S. Hoffman Machinery Corporation Air Appliance Division New York, New York	Hoffman Dust Separators	Vertical cloth dust tubes, standard sizes 38 to 586 sq.ft. for central and portable vacuum cleaning systems. Rotary arm reverse-jet unit also available.	Manual shaking at top of dust tubes. Reverse-jet
Western Precipitation Corporation Los Angeles, California	Dualaire Dust Collector	Dual vertical felt bags with traverse rings, standard sizes in multiples of 102 to 211 sq.ft.	Reverse air jet operating through traverse ring.

* Collection on inside of bag on all collectors except those marked with double asterisk.
** Collection on outside of bag or envelope.

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*From Billings, C.E., M.W. First, R. Dennis, and L. Silverman, Laboratory Performance of Fabric Dust and Fume Collectors, U.S. Atomic Energy Commission, Report NYO-1590, pp. 114, Harvard University Air Cleaning Laboratory, August 31, 1954.

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS - 1961*

Manufacturer	Trade Name	Characteristics[a]	Method of Cleaning
American Air Filter Co., Inc. 215 Central Avenue Louisville, Kentucky	Amerjet	Vertical cloth dust tubes with traverse ring, standard sizes 85 to 2390 sq.ft.	Reverse air jet operating through traverse ring.
	Glass Cloth Collector	Vertical glass cloth tubes for high temperatures, standard sizes 1312 to 7130 sq.ft.	Pneumatic collapse.
	Airmat Arrester	Verticel panels of paper or fabric# held in frames, units of 150 to 6000 cfm.	Frames rapped at bottom by manual or motor vibrator.
Blaw-Knox Co., Inc. 300 6th Avenue Pittsburgh 22, Pa.	Blaw-Knox Framed Bag[b]	Framed bags#, standard sizes 560 to 30,080 sq.ft.	Bag frames rapped by beaters, vibrated by motor drive.
Day Company P.O. Box 25 Minneapolis 40, Minnesota	Type "AC"	Vertical felt dust tubes with traverse ring, standard sizes 51 to 1218 sq.ft.	Reverse-air jet operating through self-adjusting traverse ring.
	Type "RJ"	Vertical felt dust sleeves# with quick-opening butterfly valves, standard sizes 58 to 640 sq. ft.	High velocity reverse air from pressure blower through quick opening valve.
Dracco Division Fuller Company 4063 East 116th St. Cleveland 5, Ohio	Multi-Bag Filter Uni-Bag Filter Glass Bag Filter	Vertical cloth dust tubes, standard sizes 800 to 16000 sq.ft., glass bags and special filters to 500,000 sq.ft.	Back flow air supplied in automatic type. Sonic cleaning used with glass bag and special types.
Ducon Company 147 East 2nd Street Mineola, L.I., N.Y.	UFV Bin Vent Filter	Vertical cloth dust tubes, 15 to 156 sq.ft.	Manual shaker at top.
	UFS, M, A	Same, 60 to 1830 sq. ft.	UFA with shake and back flow air.
	Uniflow Backwash	Vertical dust tubes open at both ends.	Alternating pulses of back flow and primary air.
	FD	Fiber dust bag filter, 50 to 400 sq.ft.	Turn bag inside out.

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*Billings, C.E., M.W. First, R. Dennis, L. Silverman, Laboratory Performance of Fabric Dust and Fume Collectors, U.S. Atomic Energy Commission Report No. NYO-1590, Harvard University Air Cleaning Laboratory, Revised January 1961.

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS - 1961 (Continued)

Manufacturer	Trade Name	Characteristics[a]	Method of Cleaning
Dustex Corporation P.O. Box 2520 Buffalo 25, N.Y.	Roto-Jet	Vertical felt dust tubes# with rotary arm reverse-jet air tube, standard sizes 40 to 800sq.ft.	Reverse-air jet operating through interior longitudinal rotating blow tube.
	Inductaire	Vertical cloth dust tubes# with pressure jet nozzles, standard sizes 720 to 40,000 sq.ft.	Reverse flow plus pressure jet.
Flex-Kleen Corp. 406 S. Plymouth Court Chicago 5, Ill.	Flex-Kleen	Vertical cloth dust tubes# with compressed air nozzles in outlet header, standard sizes 206 to 1200 sq.ft.	0.1 sec. pulse of 100 psi compressed air per min. (2 scfm/1000 cfm)
John Wood Company Bernardsville, New Jersey	John Wood Fabric Filter Shaker-Envelope	Cloth dust envelopes#. Standard sizes 250 to 1000 sq.ft.	Manual or automatic shaking.
	Shaker-Tube	Vertical cloth dust tubes, standard sizes 940 to 6210 sq.ft.	Automatic shaking with reverse flow.
	Reverse-Flow Tube	Vertical cloth dust tube, standard sizes 6000 to 8000 sq.ft.	Automatic backflow air and flex collapse.
Kindt-Collins Co. 12651 Elmwood Ave. Cleveland 11, Ohio	Model 550 Master Dust Collector	Single cloth dust bag for unit type dust control,size approx. 30 sq.ft.	Shut off flex cleans.
	Model 1200 Master Dust Collector	Cloth covered wire mesh screen frame# for unit type dust control, size approx. 600 sq.ft.	Manual shaking.
Kirk & Blum Manufacturing Co. 2808 Spring Grove Ave. Cincinnati 25, Ohio	Type W-Unit Collector	Single vertical cloth bag approx. 900 cfm.	Flex to clean.
G.A. Kleissler Co. 126 Gotthart St. Newark 5, N.J.	Kleissler Filter Dust Separator	Vertical cloth dust tubes, standard sizes 100 to 15,672 sq.ft.	Mechanical shaking at top of dust tubes.
Koppers Co., Inc. Dust Filter Dept. Baltimore 3, Md.	Aeroturn Dust Filter	Vertical felt dust tubes with traverse ring, standard sizes 90 to 6400 sq.ft.	Pressure controlled reverse-air jet operating through self-adjusting traverse ring.
Lamson Corp. Syracuse 1, N.Y.	Exidust	Vertical cloth dust tubes, standard sizes 38 to 727 sq. ft., for central vacuum cleaning systems.	Manual shaking at top of dust tubes.

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS -1961 (Continued)

Manufacturer	Trade Name	Characteristics[a]	Method of Cleaning
MacLeod Company P. O. Box 452 Cincinnati 41, Ohio	MacLeod Dust Collector	Cloth tube and screen* types, standard sizes 160 to 13,300 sq.ft.	Mechanical shaking of tube type, mechanical rapping of screen type.
Northern Blower Div. Buell Engrg. Co. 6409 Barberton Ave. Cleveland, Ohio	Norblo Standard Type	Vertical cloth dust tubes, standard sizes 960 to 16,128 sq.ft.	Mechanical or compressed air shaking at top of dust tubes.
	Norblo Automatic Type	Same, compartmented, 960 to 15,552 sq.ft.	Same, compartmented cleaning.
	Norblo Portable, Semi	Similar, unit type, 36 to 720 sq.ft.	Manual or mechanical shaking at top.
	Norblo AG, ALG	6"x9' or 11½"x30' glass bags.	Back flow air collapse flex.
Pangborn Corp. Hagerstown, Md.	Type "CH-2"	Cloth covered wire mesh screen frames*, standard sizes 1080 to 29,900 sq.ft.	Mechanical rapping of frames with beaters.
	Type "CH-3" Self-Cleaning	Cloth covered wire mesh screen frames*, standard sizes 400 to 14,100 sq.ft.	Reverse air flow through integral traversing blower.
	Type "CM"	Vertical multiple cloth tubes or bags, standard sizes 1360 to 21,760 sq.ft.	Mechanical shaking at top of tubes.
	"CN" Unit Type	Vertical multiple cloth tubes or bags, standard sizes 200 to 1000 sq.ft.	Mechanical shaking at top of tubes.
	Type "CO" Pressure-Jet	Vertical cloth tubes 6" to 11½" dia. adaptable to high temp. service.	Combination pressure-jet and reverse air cleaning.
Parsons Engrg. Co. 4592 Seidler Road Willoughby, Ohio	Oval Bag Dust Arrestor[c]		
Pulverizing Machinery Div. American-Marietta Co. Chatham Road Summit, New Jersey	Mikro-Collector	Vertical felt dust tubes with traverse rings, standard sizes 19 to 3360 sq.ft. in modules of 130 sq.ft.	Reverse-air jet operating through traverse ring.
	Mikro-Pulsaire	Vertical felt dust tubes* with Venturi and compressed air nozzle in outlet header, standard sizes in multiples of 170 sq.ft.	0.1 sec. pulse of 100 psi compressed air per min. (2 scfm/1000 cfm).

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS - 1961 (Continued)

Manufacturer	Trade Name	Characteristics[a]	Method of Cleaning
Rees Blow-Pipe Manufacturing Co. 2929 Fifth Street Berkeley 10, Calif.	Rees Dust Arrestor	Vertical cloth dust tubes, standard sizes 300 to 15,000 sq.ft. approx.	Mechanical shaking at top of tube with electric driven or air motor driven shaker. Back flow air cleaning in addition to shaking available in automatic types. Where glass or other non-natural fiber filter fabrics use non-shaking bag collapse.
Ruemelin Manufacturing Co. 3860 North Palmer Milwaukee 12, Wis.	Tubular Type Dust Filter Standard and Automatic	Vertical cloth dust tubes, standard sizes 1000 to 9155 sq.ft.	Mechanical shaking at top of dust tube. Compartmented cleaning in automatic.
	Tubular Type, Assembled and Portable Units	Same, for unit dust control, 53 to 755 sq.ft.	Manual or mechanical shaking.
W. W. Sly Manufacturing Co. 4700 Train Ave. Cleveland 1, Ohio	Intermittent or Automatic Continuous Filter	Cloth bags on screen frames*, standard sizes 748 to 1570 sq.ft.	Bags shaken mechanically at end. Cyclic compartmented cleaning in continuous type.
	Dynaclone	Similar special type bags* standard sizes 748 to 8976 sq.ft.	Back flow cleaning air supplied from outside through travelling roller plenum.
	Unit Filter	For unit dust control, 242 to 1496 sq.ft.	Manual or mechanical shaking.
	Economy Filter	Similar, 176 to 352 sq.ft.	Same
	Glass Cloth Filter	Compartmented bags	Reverse air flex.
Smico, Inc. 500 N. MacArthur Blvd. Oklahoma City, Oklahoma	Smico Suction Filter	Vertical cloth dust tubes, standard sizes 380 to 2280 sq. ft., 18-5" tubes per compartment.	Tubes in each compartment lifted and dropped with simultaneous back flow air.
Standard Electrical Tool Co. 2488 River Road Cincinnati 4, Ohio	Grind-Air-Rester	Unit type dust collector, with vertical envelopes*, standard capacities 240 to 800 cfm.	Manual shaking at bottom of envelopes.

PRINCIPAL U.S. MANUFACTURERS OF CLOTH FILTER DUST AND FUME COLLECTORS - 1961 (Continued)

Manufacturer	Trade Name	Characteristics[a]	Method of Cleaning
Sterling Blower Co. 791 Windsor St. Hartford, Conn.	Type "R" Dust Collecting Unit	Vertical cloth dust tubes, standard sizes 111 to 552 sq.ft.	Bags rapped at bottom.
Torit Manufacturing Co. 1133 Rankin St. St. Paul 16, Minn.	Torit Dust Collector	Vertical cloth envelopes*, for unit type dust control, standard sizes 30 to 800sq.ft.	Manual or automatic shaking at bottom of compartment.
	Torit Automatic Dust Collector	Vertical cloth dust tubes, standard sizes 380 to 2280 sq.ft.; 18 tubes per compartment.	Tubes in each comparment lifted and dropped with simultaneous back flow air.
U.S.Hoffman Machinery Corp. Air Appliance Div. 103 Fourth Ave. New York 3, N.Y.	Hoffco-Vac Filter Dust Collector	Vertical cloth dust tubes, standard sizes 18 to 905 sq.ft.	Manual or automatic shaking.
Western Precipitation Division Joy Manuf. Co. P.O.Box 2744 Los Angeles 54, California	Dualaire Dust Collector	Dual vertical felt dust tubes with traverse rings, stnadard sizes in multiples of 226 to 514 sq.ft.	Reverse-air jet operating through traverse ring.
	Therm-O-Flex	Glass bags, standard sizes in multiples of 62 to 75 sq.ft. to any maximum.	Back flow air collapse flex, cyclic compartmented cleaning.
Wheelabrator Corporation Mishawaka, Ind.	Dustube Collector	Vertical cloth dust tubes, standard sizes 940 to 11,750 sq.ft.	Mechanical shaking at top of dust tubes.
	Automatic Continuous	Same, compartmented cleaning.	Same, cyclic compartmented cleaning.
	Assembled Units A,B	Same, for unit dust control, 90 to 720 sq.ft. Standard unit adaptable for glass cloth or filter aid.	Manual or mechanical shakers, special cleaning.

a. Dust collection on inside of bags on all collectors except those marked with an asterisk (*), where collection is on outside of bag or envelope.

b. Taken from an earlier listing, present manufacturing capability unknown, no response to inquiry.

c. Taken from ASME listing, no response to inquiry.

APPENDIX 1.4

ESTIMATED 1968 AND 1969 FABRIC FILTER SALES

An estimate of the 1968 and 1969 sales of each of the U.S. producers of fabric filters is presented in Table 1. Public financial data and business publications were examined to obtain the reported total annual sales and estimates of air pollution control equipment sales shown in columns 2 and 4 of Table 1.

An estimate of the relative fraction of total sales for 1969 due to fabric filters was made as shown in columns 6 and 8. The estimate for % of total sales was applied to the reported or estimated 1969 total sales to yield the probable fabric filter sales shown in column 7, unless no publically available information was located, in which case it was assumed the producer had 1969 sales of $100,000. For example, in line 5, American Air Filter reported 1969 sales of the order of $82 million (J.V. Sherman, Barron's, 16 February 1970), of which 21% was stated to be in air pollution control equipment. Since this producer has a well-developed broad product line and major market position, it was assumed (conservatively) that of the order of 1/5 of reported APCE sales were likely to be fabric filters. This is approximately 4% of total sales, or $3.3 million for 1969. Estimates, or similar arguments, were applied to each producer as shown in column 6 leading to estimated fabric filter sales shown in column 7. These estimates are believed to be reasonably conservative. Total annual sales for 1969 are thus estimated to be $55.5 million.

The individual producers marked with an asterisk in Table 1 are members of the Industrial Gas Cleaning Institute, the industry trade association. The sales of these companies as estimated above, are shown separately in Table 2, substantiating the statement made by Wilson, the president of IGCI (1967) that IGCI member sales represent about 75% of total APCE sales.*

Figures 1 and 2 show the relationships between the number of employees of fabric filter manufacturers and reported sales volumes (all products) for the years 1968 and 1969. Aggregate 1969 sales of all producers where

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*Statement of E.L. Wilson, President, Industrial Gas Cleaning Institute, in Air Pollution - 1967 Air Quality Act Hearings, U.S. Senate, Ninetieth Congress, First Session; on S. 780, Part 4, page 2629.

Table 1

ESTIMATED FABRIC FILTER SALES VOLUME BY MANUFACTURER

Manufacturer	Estimated or Reported Total Sales 1968 Sales $10^6$$	Empl.	1969 Sales $10^6$$	Empl.	Estimated 1969 Fabric Filter Sales % Sales	$10^6$$	% Total FF Sales	Remarks, Other Products	Exchange Listed[a]
Ace-Sycamore, Inc.	--	--	--	--	--	0.1	0.2	-	--
Aerodyne Mchy. Corp.	--	--	2	50	--	0.1	0.2	Material handling equipment	--
Aget Mnfg. Co.	--	--	--	--	--	0.1	0.2	-	--
Air Preheater Div.*	--	1150	( )	1150	--	0.1	0.2	Heat exchangers, fans	N
American Air Filter*	72[b]	3500	82[b]	3600	4	3.3	5.9	Heating/vent'g/air conditioning fans, 21% air poll'n. control equip.[b] 1/5 fabric filters, est.	N
Bahnson Co.	--	600	--	(600)	--	0.1	0.2	Textile machinery	--
Buell Eng'g. Co., Inc.*	12	350	12	(350)	25	3.0	5.4	Materials handling equipment	--
Buffalo Forge Co.*	50	2000	50	2000	2.5	1.2	2.2	Heating/vent'g/air conditioning fans, pumps, machine tools	N
Carter-Day Co.	10	375	10	375	10	1.0	1.8	Materials sizing, handling, storage tanks	O

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[a] Parent Company stock for Divisions indicated, N = NYSE, A = ASE, O = OTC; - data on public distribution of ownership not located.

[b] J.V. Sherman, Barron's, Feb. 16, 1970.

*Member IGCI

Table 1 (Continued)

Manufacturer	Estimated or Reported Total Sales 1968 Sales 10^6\$	1968 Empl.	1969 Sales 10^6\$	1969 Empl.	Estimated 1969 Fabric Filter Sales % Sales	10^6\$	% Total FF Sales	Remarks, Other Products	Exchange Listed[a]
Cinci. Fan Vent. Co.	--	--	--	--	--	0.1	0.2	--	--
R.F. Cox Assoc.	--	--	--	--	--	0.5	0.9	--	--
Dracco-Fuller*	60	2800	60	2800	10	6.0	10.8	Materials handling, fans, kilns, mills, etc.	N
Ducon Co., Inc.*	--	--	--	--		1.0	1.8	--	--
Dustex Corp.*	7.6	700	11.5	700	10	1.2	2.2	Electro-mechanical equipment, instruments, parts	A
Dusty Dustless	--	--	(0.5)	(15)	90	0.5	0.9	--	--
Env. R. Corp.	--	--	--	--	--	0^+	0^+	--	--
Hoffman A.F. Div.	12	360	12	360	10	1.2	2.2	Industrial vacuum engineering systems, blowers, separation equipment	0
Hydromation E. Co.	12	--	12	--	--	0.1	0.2	Washers, automatic	--
Johnson-March Corp.	--	--	--	--	--	0.1	0.2	--	--
Kice Met. Prod. Co.	--	--	--	--	--	0.1	0.2	--	--
Kindt-Collins Co.	3	--	3	--	--	0.1	0.2	Pattern shop supply, machinery	--
Lamson Div.	17	1115	17	1115	10	1.7	3.1	Pneumatic disposal systems, conveyors, blowers	N
Macleod Co.	--	--	--	--		0.1	0.2	--	--
W.W. Meyer & Son	--	--	--	--		0.1	0.2	--	--

Table 1 (Continued)

Manufacturer	Estimated or Reported Total Sales				Estimated 1969 Fabric Filter Sales			Remarks, Other Products	Exchange Listed[a]
	1968		1969						
	Sales 10^6\$	Empl.	Sales 10^6\$	Empl.	% Sales	10^6\$	% Total FF Sales		
Pangborn Corp.*	30	1000	45[b]	(1500)	20	9.0	16.2	Blast cleaning equipment; 1/5 fabric filters, est.	N
Perlite Corp.	--	--	--	--		0.1	0.2	--	--
Precipitaire Div.*	(16)	(700)	--	25		0	0	--	0
Pulverizing M. Div.*	14	300	18	480	20	3.6	6.3	Pulverizing equipment, 1/5 fabric filters, est.	A
Rees BP Mnfg. Co.	--	--	--	--		0.5	0.9	--	--
Research-Cottrell*	41[b]	500	58[b]	600	10	5.8	10.4	Air pollution control equipment; 1/10 fabric filters, est; 20% of fabric filter market[b]	A
Ruemelin Mnfg. Co.	--	--	--	--	--	0.3	0.5	Sand blasting machinery	--
Systems Eng. Div.	6	175	14	350	--	0.1	0.2	Valves	--
Setco Ind.	( )	( )	( )	(100)	--	0.1	0.2	Grinding machinery, lathes, machine tools	--
WW Sly Mfg. Co.	5	180	6	200	25	1.5	2.7	Foundry cleaning equipment, 1/4 fabric filters, est.	--
Sprout-Waldron Co., Inc.	20	900	25	975	--	0.1	0.2	Materials handling, pulp and specialty machinery	--
Sterling Blower Co.	--	--	--	--	--	0.1	0.2	--	--

Table 1 (Continued)

Manufacturer	Estimated or Reported Total Sales 1968 Sales $10^6\$$	1968 Empl.	1969 Sales $10^6\$$	1969 Empl.	Estimated 1969 Fabric Filter Sales % Sales	$10^6\$$	% Total FF Sales	Remarks, Other Products	Exchange Listed^a
Steinvent Co., Inc.	--	--	--	--	--	0.1	0.2	--	--
Tailor & Co., Inc.	--	--	--	--	--	0.1	0.2	--	--
Torit Corp.*	4	150	(4.5)	(165)	66	3.0	5.4	Laboratory equipment	--
United McGill Corp.	17	650	17	650	1	0.2	0.4	Pressure vessels, structures; heating, vent'g, air conditioning	O
UOP Air Corp. Div.*	--	--	(2.7)	(100)	10	0.3	0.5	--	N
Western Precip. Div.*	--	--	24^b	275	20	4.8	8.7	Air pollution control equipment, 1/5 fabric filters, est.	N
Wheelabrator Corp.*	76^b	3500	82^b	3500	5	4.1	7.4	Abrasive blast cleaning equip; 20% air poll'n control equip.,^{b} 1/4 fabric filters, est.	A
Young Mchy. Co.	3	100	3	100	--	0.1	0.2	Materials handling equipment, pulverizing mills	--
					TOTAL	55.5	100.6		

Table 2

ESTIMATED FABRIC FILTER SALES OF MEMBERS OF THE IGCI (1969)[*]

	1969 Sales	% of Total Sales Estimated in Table 1
Air Preheater Div.	0.1	0.2
American Air Filter	3.3	5.9
Buell Engineering Co., Inc.	3.0	5.4
Buffalo Forge Co.	1.2	2.2
Dracco-Fuller	6.0	10.8
Ducon Co., Inc.	1.0	1.8
Dustex Corporation	1.2	2.2
Pangborn	9.0	16.2
Precipitaire Div.	0	0
Pulverizing Machinery	3.6	6.3
Research Cottrell	5.8	10.4
Torit Corporation	3.0	5.4
UOP Air Corr. Div.	0.3	0.5
Western Precip. Div.	4.8	8.7
Wheelabrator Corporation	4.1	7.4
	46.4	83.4

[*] Taken from Table 1.

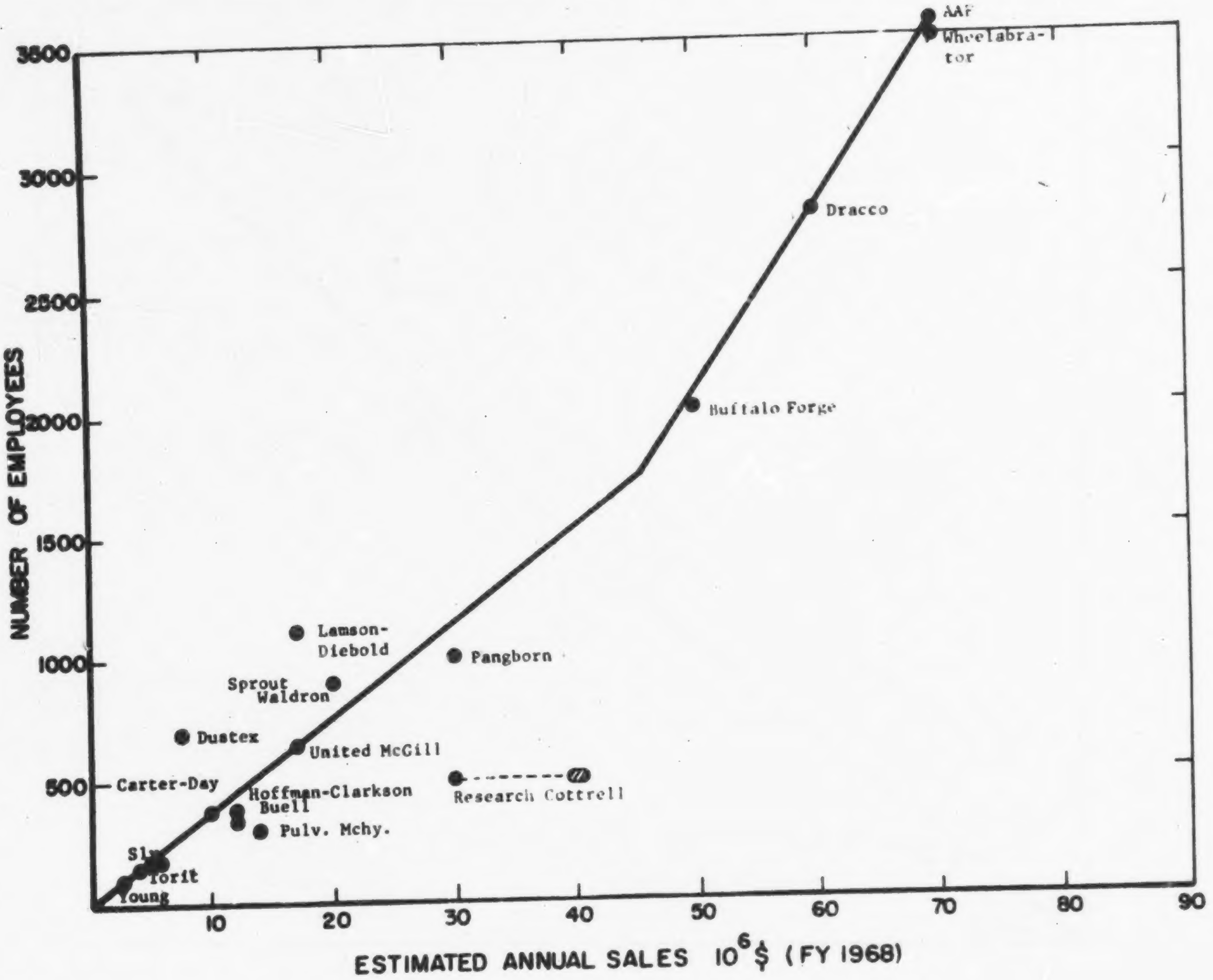

Figure 1. Relationship Between Estimated Annual Sales and Total Number of Employees of Fabric Filter Manufacturers (1968)

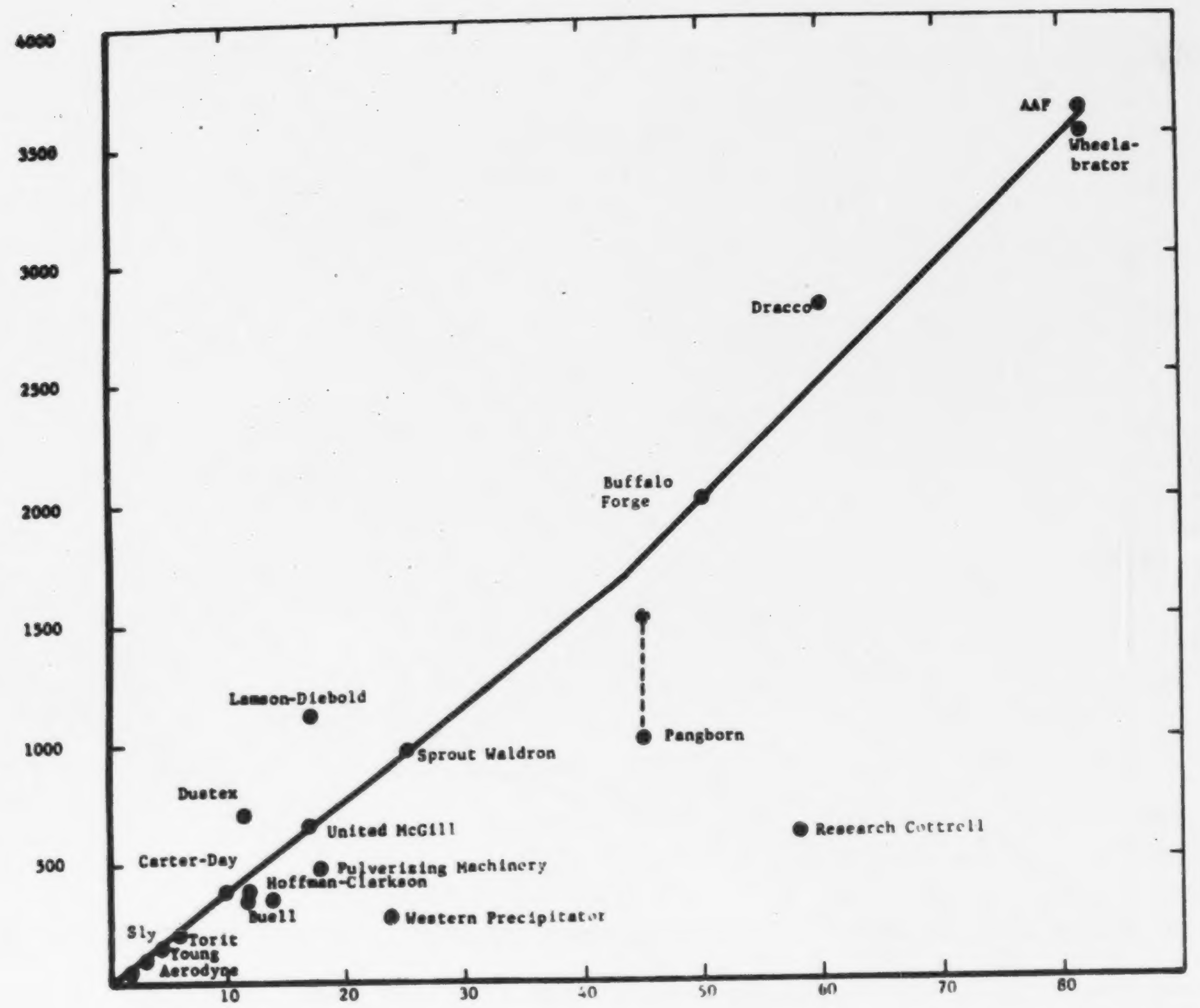

Figure 2. Relationship Between Estimated Annual Sales and Total Number of Employees of Fabric Filter Manufacturers (1969)

sales data were publicly available (22 firms) totaled $557 million, representing reported employment of 20,245 persons. Based on estimated fabric filter sales of $55.5 million, fabric filters represent about 10% of the reported total sales volume.

APPENDIX 1.5

ESTIMATE OF THE FABRIC FILTER MARKET

In order to obtain an estimate of the number of individual fabric filters in use during the year 1969, previous data on industry growth and sales were plotted as shown in Figure 1 and extrapolated back to 1910, the assumed beginning of commercial production in any quantity. Numbers of fabric filter manufacturers were estimated from Curve A in Figure 1, as shown in column 2 of Table 1. Estimates of probable annual sales were obtained by year from the extrapolation of Curve C, Figure 1, as presented in column 3 of Table 1 (at average mature industry growth rate, Curve B).

The number of square feet of fabric represented by these estimated annual sales was assumed to be represented by a gross average (1910-1970) cost figure of $1 per square foot. Figure 2 illustrates the trend in costs per square foot of filter surface from 1940 on, as presented by the various sources indicated. In the 1940's fabric filter systems tended to be relatively small (less than 1000 sq. ft. on average), and intermittently cleaned units were commonly employed. The average size of commercially produced fabric filters (sq. ft. of cloth area per unit sold) has tended to increase with the wider range of applications to which fabric filters have been applied. Average filter size in the 1966-1968 period was estimated, from two independent sources, to be around 3000 sq. ft.

Figure 2 also indicates trends in costs as depending on cloth area. The trend to multi-compartmented automatic units is evident in cost data shown for around 1949-1950, resulting in slightly higher costs associated with automatic dampers for periodic compartment closures, automatic rappers or shakers, and programmed time or pressure operated switch gear. The average air to cloth ratio in these applications was generally in the range of 2-4 cfm. After 1950, the impact of continuous automatic reverse jet technology resulted in smaller amounts of cloth (~10 times more air volume handled per unit cloth area), but more mechanical parts so the cost per square foot rose by a factor of nearly 10, as illustrated for the 1965-66 cost data.

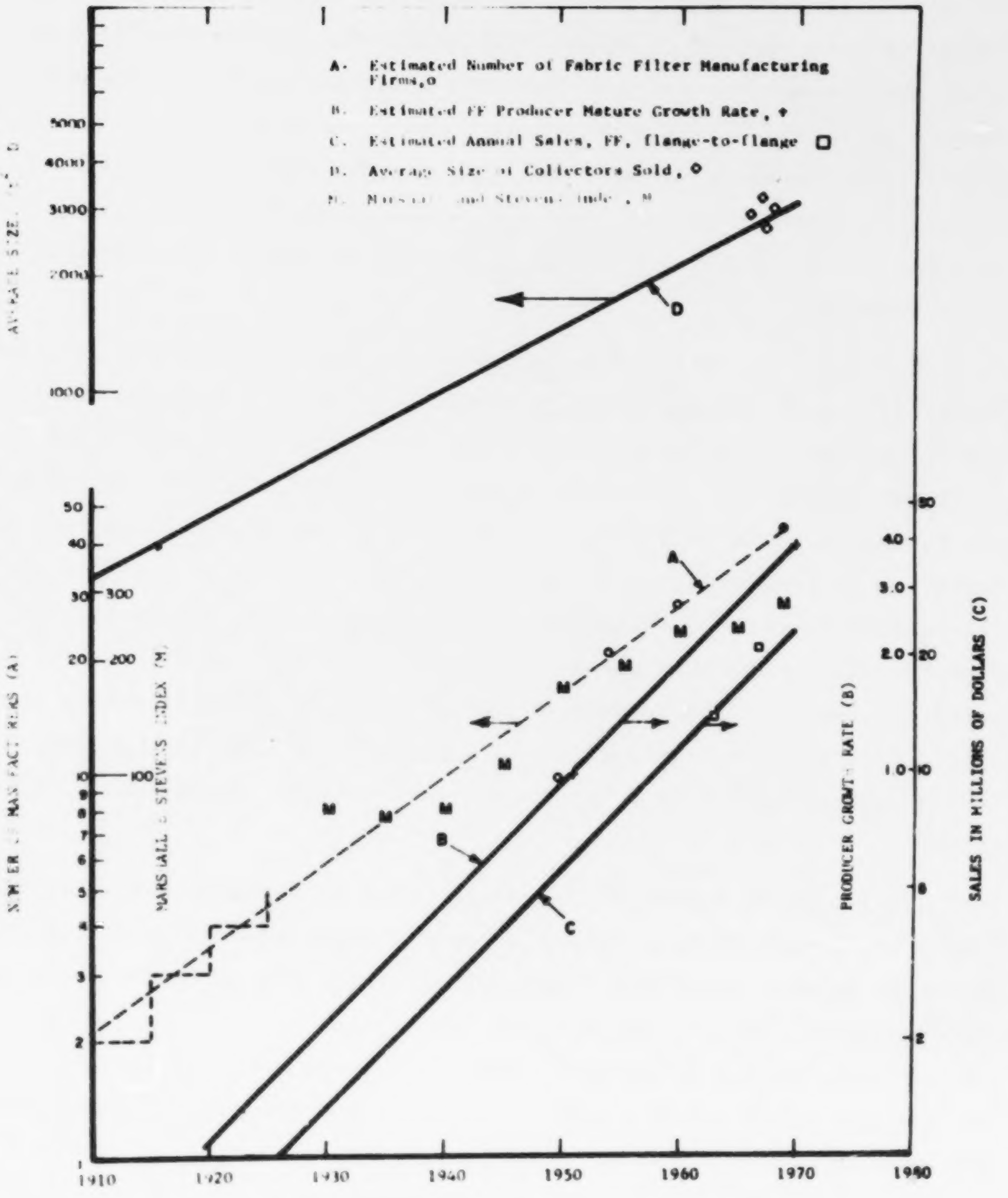

Figure 1. Estimated Growth of Fabric Filter Manufacturing (1910-1969)

TABLE 1

ESTIMATED* NUMBER OF FABRIC FILTERS SOLD, BY YEAR

YEAR	Est.No. FF Mfrs.	Est.Ann.Sales 10^6 $	Est.Cum.No. sq.ft. sold	Ave. Size ft^2	Est.Ann.No. FF Sold	Est. Cum. No. FF
1910	2	(0.31)	0.31	400	(775)	775
1920	4	0.64	5.07	600	1065	12140
1930	6	1.33	14.89	800	1670	27950
1940	10	2.75	35.21	1000	2750	51390
1945	13	3.95	52.46	1200	3300	66790
1949	16	5.30	71.51	1400	3790	81160
1950	17	5.65	77.16	1450	3900	85060
1955	21	8.10	112.41	1750	4630	106,640
1960	28	11.70	163.11	2100	5580	132,200
1961	29	12.50	175.61	2200	5700	137,900
1962	31	13.40	190.01	2300	5830	143,730
1963	32	14.50	203.51	2400	6050	149,780
1964	34	15.50	219.01	2500	6200	155,980
1965	35	16.60	235.61	2600	6390	162,370
1966	37	18.00	253.61	2650	6800	169,170
1967	40	19.20	272.81	2700	7120	176,290
1968	42	20.50	293.31	2850	7200	183,490
1969	44	22.50	315.81	3000	7500	190,990

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* Most conservative estimate, based on 1963, 1967 BDSA estimates of annual sales of FF, and IGCI summary of numbers of FF sold, 1966-1967.

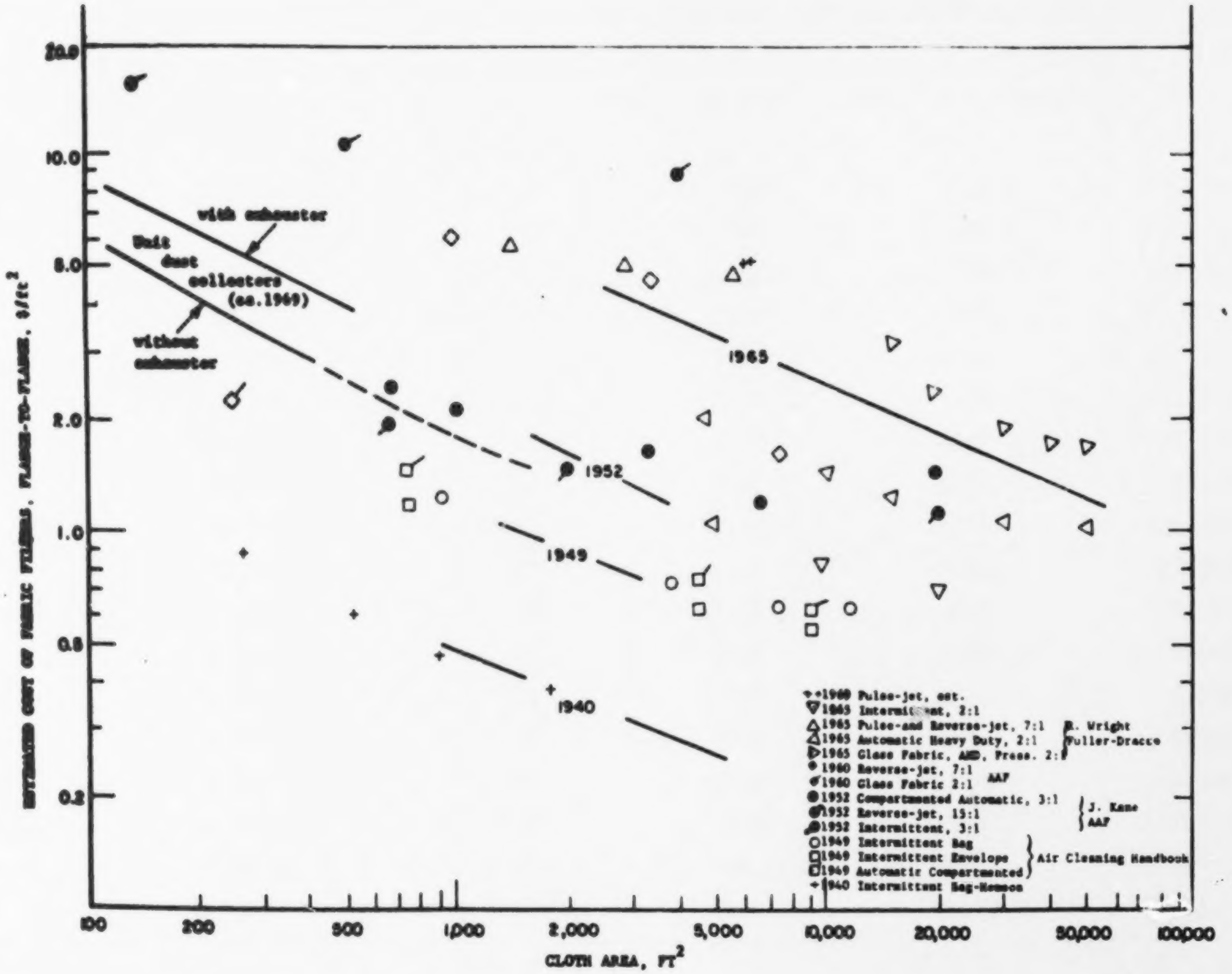

Figure 2. Trends in Cost of Fabric Filters, \$/ft^2

The increasing complexity of applications and designs currently available is illustrated by the several cost data points for the period 1960-1970. For example, the relative costs of intermittently cleaned collectors have increased by a factor of approximately 2 during the past 30 years. However, the figures tend to group around $1 per square foot. Due to the changing technology and lack of knowledge on the distribution of sales of the range of filter systems, it is assumed that an average cost of $1 per square foot represents a reasonable compromise across the 60 year period.

This estimate was applied to the estimated annual sales from 1910 onward (column 3, Table 1) to provide an estimate of total annual filter area sold. To reduce this to a reasonable consistent estimate of the number of fabric filter collectors sold per year, the estimated average size of collector sold per year (Curve D, Figure 1) was applied to the cloth area represented by the annual sales volume, as shown in columns 5 and 6, Table 1.

The estimated cumulative number of fabric filters sold from 1910 onward is shown in column 7 of Table 1, approximately 190,000 fabric filters. It is further assumed that all collectors produced prior to 1949 are no longer in use as a consequence of obsolescence, changes in technology, etc. The 1949 figure (81160) is subtracted from the 1969 figure to yield a probable estimate of fabric filters in use in 1969 of order 100,000 units. The uncertainty associated with this estimate includes the inability to estimate total sales within a factor of 2 (the lower sales figures of Figure 1.12 of Volume 1 of this contract report, provided by BDSA, were used in the extrapolation of sales) and the uncertain mortality of fabric filter use.

These estimates and a replacement rate of 5 percent (20 year life) would result in a 1969 annual replacement sales of the order of 4000 units (0.05 x 81,160,-1949). In addition, increasing applications associated with changes in industrial production technology, air pollution control pressures, etc., would undoubtably account for the remainder of the 7500 or so units estimated to have been sold in 1969.

The estimated number of fabric filters in use given in column 7 of Table 1, can be compared with statements of sales in manufacturers' literature. For example, one manufacturer referred in a 1957 brochure to "over 40,000 ... dust filters now in use..." Another manufacturer stated in 1956 product literature "More than 35,000 ... dust collectors are now in use." By such comparisons it is concluded that the estimate of 100,000 fabric filters in use is a reasonably conservative one.

A gross estimate of the total air and gas volume being treated by fabric filters in 1969 can be obtained by estimating the average air-to-cloth ratio, and applying this to the total cloth area estimated to be presently in use, 243×10^6 square feet. (Table 1, column 4, line 1969 minus line 1949). If the average air-to-cloth ratio is 3 cfm/sq. ft., the total volume of air being treated by fabric filters is of the order of 750×10^6 cfm.

An estimate of the fabric market can be obtained as the sum of fabric for new filters and replacement fabric. Estimated fabric sold annually with new collectors is of the order of 20×10^6 sq. ft.. Replacement at the rate of all fabric in three years gives 80×10^6 sq. ft. per year, for a total annual rate of 100×10^6 sq. ft. Considering all types of fabric, this would be approximately 10×10^6 pounds annually (about one thousandth of the annual sales of all textiles). An average fabric is assumed to cost of the order of \$3 yd^2 fabricated into filter elements ready to install. This yields an estimated \$33 million for the fabric market associated with new product installations and replacements, again with an uncertainty factor of perhaps 2. The size of the filter fabric market is thus of the same order of magnitude as the annual sales of fabric filters.

APPENDIX 1.6

FABRIC FILTER APPLICATIONS IN THE NON-METALLIC MINERALS INDUSTRY

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The applications of dust collectors in the non-metallic mineral industry (NMMI) were surveyed in 1967 by Pit and Quarry Publications, Inc., publishers of a major trade journal in the industry.* Kostka, in describing the survey methodology, indicates:

> "Questionnaires were sent to 2,250 producers picked at random from our circulation list. The following is the number of questionnaires sent to each segment of the industry:
>
> | | |
> |---:|---|
> | 140 | Cement |
> | 1,200 | Crushed stone |
> | 55 | Gypsum |
> | 70 | Industrial sand |
> | 150 | Lightweight aggregate |
> | 80 | Lime |
> | 65 | Talc |
> | 500 | Miscellaneous |
> | 2,250 | TOTAL |
>
> "Replies were received from 374 producers, representing a 16.5 percent return.
>
> "Because the use of dust collectors in crushed stone operations is much less concentrated than it is in some of the other segments of the non-metallic minerals industry, a higher number of questionnaires were sent to this segment. This made it possible to pick up replies from enough crushed stone producers using dust collectors to come to some logical conclusions about their use in plants of this type."

Table 1 presents an estimate of the total number of dust collectors in use in the NMMI projected from the 16.5 percent return. It indicates 13,347 collectors being used in 6,252 plants, and a total industry investment of $351,000,000. Fabric filters are estimated at 7,454 units or 56 percent of the number of collectors in use. This estimate compares favorably with an IGCI figure of 56 percent of sales for filters sold in 1967 as summarized in Table 1.5 of Volume I of this report.

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*Kostka, J.G., Dust Collector Survey, Pit and Quarry Publications, Inc., Chicago, Ill. (1968).

Table 1

PROJECTED ESTIMATE OF DUST COLLECTORS IN USE IN THE NON-METALLIC MINERALS INDUSTRY BY TYPE AND TOTAL VALUE[*]

	Bag	Mechanical (Dry)	Electro-static Precipitator	Scrubber	Estimated Value
Cement[**]	2,631	699	258	7	$200,192,000
Crushed Stone	712	201	0	194	14,356,930
Gypsum	844	148	34	0	7,410,000
Industrial Sand	252	196	0	0	3,080,000
Lightweight Aggregate	142	113	0	113	3,984,074
Lime	445	509	21	191	36,676,000
Refractories	207	141	10	89	19,364,000
Talc	195	13	0	0	1,020,500
Miscellaneous[***]	2,026	2,763	0	0	64,930,000
TOTAL	7,454	4,783	332	778	$351,013,500

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[*] From Kostka, J.G., *Dust Collector Survey*, Pit and Quarry Publications, Inc., Chicago, Ill. (1968).

[**] Cement distribution plants are not included; but see Table 2 of this appendix.

[***] Asphalt plant collectors are not included.

In considering replacement rate, Kostka estimates annual purchases as follows:

> "New plants, plant expansions, and modernization of existing plants should result in an annual expenditure of approximately 12 percent of the present value of dust collectors in the nonmetallic minerals industry. This amounts to about $42,121,600 a year."

As the cement component of the industry is the largest and has been estimated to be growing at the rate of 5 percent per year, the annual requirement of 12 percent seems reasonable.

Fabric filter sales for the NMMI have been estimated from IGCI data to represent $3,800,000 in 1967. This figure is less than 10 percent of Kostka's estimate for required annual investment in all types of dust collection equipment. The number of fabric filters in use in the NMMI is 7,454 estimated by the Pit and Quarry survey, and annual sales of 12 percent would amount to approximately 895 units. In contrast the IGCI survey estimate of NMMI numbers sold in 1967 was 322 units. These estimates differ by a factor of approximately 3 for a number of reasons which we haven't been able to completely explain. While the IGCI survey was directed only to air pollution control applications the Pit and Quarry survey asked whether the collector was purchased for reclaiming material, for a pollution problem, or for both purposes combined. However the responses were 7 percent, 23 percent, and 70 percent, respectively. Thus although the term "pollution problem" can have a number of interpretations the difference between surveys is apparently only 7 percent.

The Pit and Quarry report included numerous valuable statistics on equipment manufacturer, average size and size range of filters and compartments, cloth area, gas volume, fabric type, dust characteristics, dust loading, pressure drop, uses, temperature, etc. Certain data have been extracted from Kostka's report and are presented in Table 2 for further examination. Average fabric filter areas, gas volumes treated, costs, etc. are indicated for each component of the industry. The total estimated number of fabric filters (9,648) gives rise to an average col-

TABLE 2

SUMMARY OF PIT AND QUARRY SURVEY

	Cement[1]	Crushed Stone	Gypsum	Industrial Sand	Lightweight Aggregate	Lime	Refractories	Talc	Miscellaneous	Total
PLANTS										
Est. No. in U.S.	494	479[2]	114	280	168[2]	212	47	65	755[2]	
No. Surveyed[3]	53	159	7	13	24	15	7	10	70	375
Collector \$ - industry (\$x10^{6})	225	14.4	7.4	3.1	4.0	36.7	19.4	1.0	64.9	376
Collector \$ - per plant (\$x10^{3})	1,100	4.4	65	11	14	173	412	15.7	86	
APC Equipment per plant										
No. of FF:	9.7	1.48	7.4	.9	.9	2.1	4.4	3.0	2.7	
No. of Mech:	[3.8]	.09	1.3	.7	.4	2.4	3.0	.2	1.5	
No. of ESP:	[1.4]	0	.3	0	0	.1	.4	0	0	
No. of Scrubbers:	[.04]	.06	0	0	.4	.9	1.9	0	.1	
Ave FF: A/C Ratio	1.5	9.8	2.0	2.0	2.1	3.3	2.1	2.1	8.6	
Temp.	305	106	200	173	220	230	330	135	213	
ft^{2}	22,000	3,520	2,700	4,455	2,600	4,900	7,400	4,714	1,897	
CFM	33,400	34,560	5,300	8,700	5,400	16,400	15,700	8,700	16,350	
\$/CFM[4]	1.40	.50	1.25	1.20	1.25	.90	1.00	1.15	.75	
Cost (\$x10^{3})	46.6	17.3	6.7	11.5	6.7	14.7	15.7	10.0	12.3	
Total FF: Number[2]	4825	712	844	252	142	445	207	195	2026	9648
ft^{2} (x10^{6})	106	2.5	2.3	1.12	.37	2.2	1.5	.92	3.8	121
CFM (x10^{6})	161	25.6	4.5	2.2	.77	7.3	3.2	1.7	33.1	239
Cost (\$x10^{6})	225	12.3	5.7	2.9	.96	6.5	3.2	2.0	25.0	284
Mfgrs: Largest No. Installations	Norblo	Sly	Wheel.	AAF	Sly	Sly	Dracco	Parsons	Sly	
Second Largest No. Instal.	Sly	Dracco	MikroP	Pangborn	Dracco	AAF	Rees	Pangborn	Wheel.	
Fabric: Largest No. Installations	Cotton	Cotton	Dacron^{R}	Cotton	Cotton	Cotton	Cotton	Cotton	Cotton	
Second Largest No. Instal.	Dacron^{R}	Dacron^{R}	Cotton	Dacron^{R}	Dacron^{R}	Dacron^{R}	Dacron^{R}	Orlon	Orlon^{R}	

Notes to Table 2

1. All Pit and Quarry estimates for cement plants (except those bracketed) have been adjusted to include distribution as well as production plants, an increase of 2194 filters and 310 plants.
2. Plants having air pollution control equipment only. These are reported as 14.8 percent of Crushed Stone, 59.4 percent of Lightweight Aggregate, and 41 percent of all miscellaneous plants.
3. Estimated from survey statistics reported.
4. Estimated from other data, 1969 price basis.

lector size of 12,600 ft.^{2} with a range from 1,900 (miscellaneous) to 22,000 (cement). Total cloth area is estimated to be 121 x 10^6 sq. ft., gas volume 239 x 10^6 cfm, and a fabric filter investment of \$284 x 10^6, or 1.19 \$/cfm (2.35 \$/sq. ft).

In any given industry there is a variety of similar processes and operations. This is perhaps especially true of the NMMI in which about 25 different applications of fabric filters were reported. These are summarized by industry segment in Table 3 and without doubt fabric filters are used on other operations as well. Grinding, crushing, and screening were the applications most commonly reported.

Further analyses of the Pit and Quarry survey NMMI data are made elsewhere in this handbook in discussing fabric applications, cleaning methods, etc.

TABLE 3

REPORTED APPLICATIONS OF FABRIC FILTERS IN THE NON-METALLIC MINERALS INDUSTRY*

NMMI Application	Cement	Crushed Stone	Gypsum	Industrial Sand	Lightweight Aggregate	Lime	Refrac-tories	Talc	Misc.**	No. Reporting by Application	Rank
Bagging					X			X	X	3	
Bins	X		X							2	
Calcining			X		X					2	
Conveyors		X	X				X			3	
Crushing	X	X	X			X		X	X	6	2
Drying			X			X		X		3	
Elevators			X							1	
End Saw			X							1	
Expander					X					1	
General thru plant							X			1	
Grinding	X	X		X	X	X	X	X	X	8	1
Hydrators						X				1	
Kettles			X							1	
Kilns	X					X	X			3	
Loading	X									1	
Mills	X		X							2	
Packing	X		X			X				3	
Sanding									X	1	
Screens		X		X		X	X		X	5	3
Shipping					X					1	
Silos	X	X	X						X	3	
Storage			X			X				2	
Transfer	X									1	
Venting			X							1	
TOTALS:	9	4	13	2	5	8	5	4	6	56	

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*From Kostka, J.G., "Dust Collector Survey, Pit and Quarry Publications, Inc., Chicago Ill. (1968).

**Includes phosphate, kaolin, bentonite, borax, pegmatite, insulation, asbestos, fluorspar, kyanite, fuller's earth, barite, mica, asphalt, and a number of other plants.

APPENDIX 2.1

FORCE OF ADHESION BETWEEN SPHERE AND CYLINDER IN LIQUID CONTACT

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FORCE OF ADHESION BETWEEN SPHERE AND CYLINDER IN LIQUID CONTACT

Larsen* analyzed first the case of two perfectly wetted spheres (i.e., zero contact angle) with the wetted area small compared to the size of the smaller sphere. His analysis is valid for almost any sphere size ratio. Because the contact geometry for a large ratio is much like that of a small sphere on a much larger diameter fiber, Larsen then correctly inferred that his formula could be applied to fibers and smaller adhering particles, although his formula is not exact for sphere-cylinder combinations. Larsen's derivation proceeded as follows.

Surface tension of the liquid ring having radius C creates a (negative) pressure p in the fluid, giving rise to a force of adhesion

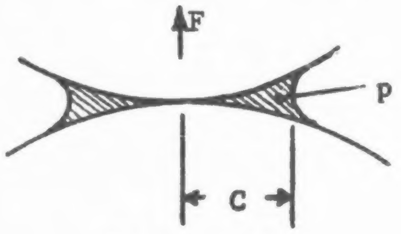

Figure (a)

$$F = \pi C^2 p \qquad (1)$$

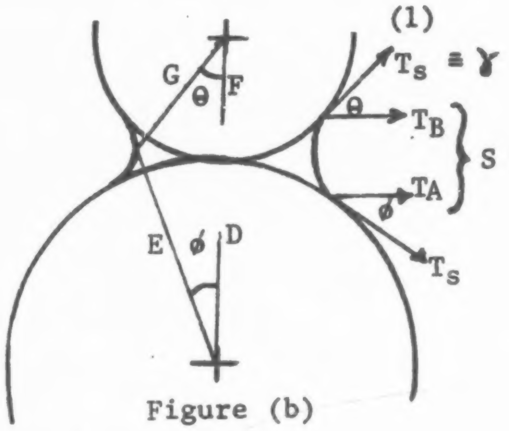

Figure (b)

The pressure can be related to surface tension T_s by analyzing the forces on an increment of the meniscus, the ends of which are tangential to each sphere. The tangential force along a length of contact m is $T_s m$, and the horizontal component T_A of that force is

$$T_A = T_s m \cos \phi = T_s m \frac{D}{E}$$

Similarly

$$T_B = T_s m \cos \theta = T_s m \frac{F}{G} \qquad (2)$$

The pressure in the fluid is the sum of these forces divided by the area S x m:

$$p = \frac{T_s \left(\frac{D}{E} + \frac{F}{G}\right)}{S} \qquad (3)$$

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*Larsen, R. I., The Adhesion and Removal of Particles Attached to Air Filter Surfaces, Am. Indust. Hyg. Assoc. Jnl., 19, 265 (1958).

However, S is related to C. Since $D^2 = (D - S_A)^2 + C^2$, as long as S_A is small (that is, as long as $S_A^2 << 2DS_A$),

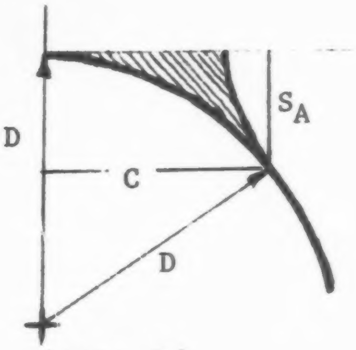


Figure (c)

$$S_A = \frac{C^2}{2D} \text{ ; and } S_B = \frac{C^2}{2F}$$

Consequently

$$S = \frac{C^2}{2}\left(\frac{1}{D} + \frac{1}{F}\right) \tag{4}$$

Equation (1) can now be evaluated:

$$F = 2\pi T_s \frac{\left(\frac{D}{E} + \frac{F}{G}\right)}{\left(\frac{1}{D} + \frac{1}{F}\right)} \tag{5}$$

It is convenient to define two ratios:

$$k_D = \frac{\text{Fiber (or larger sphere) diameter}}{\text{Particle (or smaller sphere) diameter}} = \frac{D}{F}$$

$$k_C = \frac{\text{Contact ring radius}}{\text{Particle (or smaller sphere) diameter}} = \frac{C}{F}$$

Also $E = (C^2 + D^2)^{1/2}$ and $G = (C^2 + F^2)^{1/2}$.

It is a matter of substitution to show that

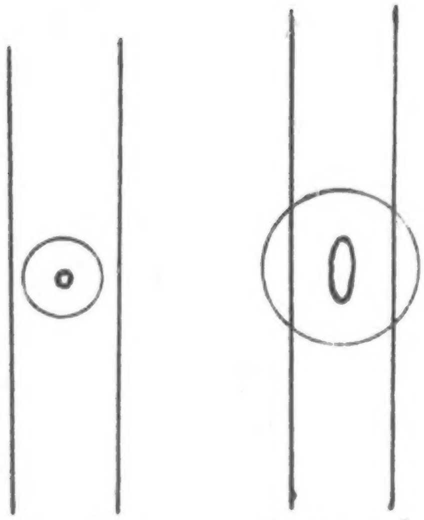
$$F = 2\pi T_s (2F) \frac{\left\{\frac{kd}{(k_C{}^2 + k_D)^{\frac{1}{2}}} + \frac{1}{(k_C{}^2 + 1)^{\frac{1}{2}}}\right\}}{\left\{\frac{2}{k_D} + 2\right\}} \tag{6}$$

which could be written

$$F = 2\pi T_s D_s k_1 \tag{7}$$

Where $D_s = 2F$ is the particle diameter and k_1 a geometric factor depending only on K_D and K_C. For the case of a particle on a plane $k_D = \infty$, and if for $k_c << 1$, k_1 becomes 1 and the force of adhesion predicted agrees with those of simpler analyses.

This result for a ring-shaped wetted area (two spheres) as shown in Figure (d) needs to be modified for the ellipse produced between sphere and cylinder. Equation (3) for pressure and the subsequent evaluation of S and the geometric factors remain unchanged since Figure (b) still represents one cross section of a sphere and cylinder. The pressure will be the same in all parts of the ellipse. However the area required for Equation (1) is no longer given by πC^2 but is now $\pi C C'$ where C', the semi major axis of the ellipse, has yet to be formulated.



Small sphere, ring contact

Large sphere, elliptic contact

Figure (d)

APPENDIX 2.2

AEROSOL ENGINEERING AND SCIENCE

AEROSOL ENGINEERING AND SCIENCE

The range of interest in aerosol systems extends to almost every field of science and technology. Studies may be directed wholly toward theoretical solutions of fundamental problems or, on the other extreme, to direct measurements of characterizing parameters in real systems. Results of these studies are published in a wide variety of specialist journals according to the subject of the research. Although the title of the journal might not suggest an association with fabric filtration _per se_, the treatment of specific aerosol systems often furnishes useful guidelines for fabric filter research. A summary listing of several scientific disciplines in which a knowledge of aerosol behavior is important is given in Table 2.2.

There is a very large body of literature relating to particulate systems and their behaviors*:

Books on Fundamentals

There is not single book that serves adequately as a text, or as an introduction, for the science of aerosols, whether in its theoretical or its experimental aspect. A fairly rigorous account of most of the fundamental properties of aerosols is provided by three classics taken together:

N. A. Fuchs, _The Mechanics of Aerosol_, Pergamon, Oxford, 1964.

H. C. Van De Hulst, _Light Scattering by Fine Particles_, Wiley, New York, 1957.

G. Herdan, _Small Particle Statistics_, Academic Press, New York, 1960.

For special topics, these may be supplemented by:

R. A. Bagnold, _Physics of Blown Sand and Desert Dunes_, Methuen, London, 1940.

S. Flugge, _Hanbuch der Physik_, Bd. 48, Geophysik II, p. 254-369 and 479-537, Springer, Berlin, 1957.

J. C. Johnson, _Physical Meteorology_, Wiley, New York, 1960.

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*This section is taken largely from an article of the same title by the late J. R. Hodkinson, in _Powder Technology_, _1_, 51 (1967), with modifications, and additions to 1970.

TABLE 2.2. RANGE OF AEROSOL SCIENCE AND TECHNOLOGY

FIELD	REMARKS
PHYSICS	
Kinetic Theory	Statistical mechanics, Brownian motion, Coagulation
Physics of Fluids	Gas dynamics, motion of particles, flow viscous flow
Electromagnetic Effects	Light scatter, laser radar Plasma physics, optical properties
Electrostatic Phenomena	Charging, ionization, motion nucleation
CHEMISTRY	
Heterogeneous Reactions	Catalysis, Combustion, Flame Chemistry
Homogeneous Reactions	Generation of particulate phase, Surface energy
PHYSICAL CHEMISTRY	
Colloid Chemistry	Study of disperse systems in fluids Agglomeration, Particle beams
Interfacial Science	Adhesion, condensation, adsorption Accommodation for flux of various molecular species
Rheology	Aerosol modification of fluid properties, non-Newtonian flow, macromolecules
Photochemistry	Smog formation, radiation chemistry, heterogeneous, homogeneous
MATHEMATICS AND APPLIED MECHANICS	
Fluid Mechanics	Flow, property, aerosol particle interactions, energy coupling and modifications of fluid transport phenomena. Turbulent flow. Physio-chemical hydrodynamics

TABLE 2.2. RANGE OF AEROSOL SCIENCE AND TECHNOLOGY (Cont)

FIELD	REMARKS
MATHEMATICS AND APPLIED MECHANICS (Cont)	
Mathematics	Slow viscous flow, sphere and cylinder problems, flow in a corner. Low Reynolds Number Hydrodynamics, drag.
ENGINEERING AND TECHNOLOGY	
Electrical	Charging, collection, device development for aerosols, control. Xerography.
Mechanical	Communication, powder technology, combustion, collection and control device development, gas dynamics in jets, gas turbines, air induction systems, clean room technology.
Aeronautical, Astronautical	Rain; ice; clouds, air induction system designs, aerosol jet-nozzle flow-energy interactions, jet propulsion, ion propulsion, interplanetary particle flux, protection, spacecraft cabin atmosphere aerosol definition, lunar dusts.
Chemical	Flow of fluids, rheology, Behaviour of disperse system, Chemical process engineering of disperse phases, Properties of aerosol systems; collection of aerosol systems, catalysis combustion, condensation, Diffusion, separations in gas-particle systems, filtering, screening, kelletizing, liquetting, lintering, fluidization and conveying of powders.
Civil	Environmental engineering, Sediment mechanics, effluent treatments.

TABLE 2.2. RANGE OF AEROSOL SCIENCE AND TECHNOLOGY (Cont)

FIELD	REMARKS
GEOPHYSICS AND ATMOSPHERIC SCIENCES	
Cloud Physics	Nucleation, condensation, fog, rain, scavenging by rain, weather modification (delib, inadvert)
Meteorology	Haze, fog, mist, transport, dispersion and disposal in the atmospheric reservoir
Atmospheric Chemistry and Radioactivity	Transport in atmosphere, formation by atmospheric processes, solar radiative interactions, photochemical smog and haze formation, deposition.
Geophysics	Geochemistry, photochemistry, chemistry and physics of the interplanetary spaces, planetary atmospheres, Light and other energy transmission in the atmosphere.
PUBLIC HEALTH AND HYGIENE	
Medicine	Inhalation, deposition, clearance, and retention of aerosols, Therapeutic aerosol generation and characterization occupational and industrial medicine, Physiological effects.
PUBLIC HEALTH - AIR POLLUTION	Industrial and occupational hygiene, health physics, atmosphereic pollution, confined compartment atmospheres, residential dwelling and public air hygiene, characterization and engineering for control or protection of residents, occupants, or workers, Clean room technology for hospital treatment of biological problems.
BIOLOGICAL AND CHEMICAL AEROSOLS	Technical applications, aerosol technology, military aerosols and agents, production, release, characterization, control, Bioengineering, Dissemination and transport of agricultural and forestry pesticides, herbicides.

B. J. Mason, Physics of Clouds, Clarendon Press, Oxford, 1959.

W. E. K. Middleton, Vision Through the Atmosphere, Univ. of Toronto, 1963.

L. Foitzik and H. Hinzpeter, Sonnenstrahlung und luftrubung, Akad. Verlag, Leipzig, 1958.

E. G. Richardson (Ed.), Aerodyanmic Capture of Particles, Pergamon, Oxford, 1960.

C. E. Lapple, Fluid and Particle Mechanics, Univ. of Delaware, 1956.

More elementary introductions to the subject or to parts of it, the first five attractively written for the layman, are:

C. Orr, Between Earth and Space, Collier Paperback, 1961.

M. Minnaert, Light and Colour in the Open Air, Dover Paperback, 1954.

B. J. Mason, Clouds, Rain and Rainmaking, Cambridge Univ. Press, 1962.

A. Assailly, Les Poussieres, Presses Universitaires de France, 1956.

G. Sutton, The Science of Flight, Penguin Books, 1955, first 70 pages (out of print)

R. D. Cadle, Particle Size: Theory and Industrial Applications, Reinhold, 1965.

A. P. Avy, Les Aerosols, Dunod, Paris, 1956.

The electrical properties of aerosols are discussed in:

H. J. White, Industrial Electrostatic Precipitation, Addison-Wesley, 1963.

Much information on the fundamental physical and chemical properties of aerosols is also to be found in the books mentioned below, as well as in the substantial compendium:

C. N. Davies (Ed.), Aerosol Science, Academic Press, New York, 1966.

for which his notebook

C. N. Davies, Recent Advances in Aerosol Science, Pergamon, Oxford, 1965.

appears to have been a preliminary sketch.

Books on Aerosol Measurement

Their titles notwithstanding, no existing book gives a comprehensive account of methods of measuring aerosols or even a general review of the physical principles that may be employed. The most widely used book at present is probably:

H. I. Green and W. R. Lane, Particulate Clouds, Spon, London and Van Nostrand, Princeton, 2nd edn., 1964.

which also contained much information on aerosol fundamentals and technology, a breadth of subject matter inevitably achieved at the expense of depth in some topics. Some of its deficiencies may be made good by reference to Davies' Aerosol Science mentioned above: and to the forthcoming publication of an extended version of

U. S. Atomic Energy Commission, Handbook on Aerosols, 1949, also see the original OSRD, NDRC, Div 10, Summary Technical Report.

The old stand-by for thirty years

P. Drinker and T. Hatch, Industrial Dust, McGraw-Hill, New York 2nd edn., 1954.

is now out of date in some aspects. The detailed

J. M. Dallavalle, Micromeritics, Pitman, London, 1948.

was especially good on particle-size distribution and sedimentation analysis; its successor, might be taken as

R. R. Irani and C. F. Callis, Particle Size: Measurement, Interpretation and Application, Wiley, New York, 1963.

The book which succeeds it, is an elementary survey:

C. Orr and J. M. Dallavalle, Fine Particle Measurement, Macmillian, New York, 1960.

Other introductory surveys of aerosol measurement are to be found in

R. D. Cadle, Particle Size Determination, Interscience, New York 1955

C. N. Davies, Dust is Dangerous, Faber and Faber, London 1954.

Air Sampling Instrument Manual, American Conference of Governmental Industrial Hygienist, 1014 Broadway, Cincinnati 2, Ohio.

The greatest deficiency in the literature on aerosol measurement is the total absence of any comprehensive and critical review of light scattering methods. Van de Hulst's excellent theoretical treatise mentioned above does not purport to discuss applications except in passing, and nearly all the chapters on light scattering books mentioned in this section are inadequate.

Books on Aerosols in the Atmosphere

The following books contain useful, if at times miscellaneous, information on aerosol science measurement and technology associated with atmospheric phenomena involving aerosols:

W. Fett, Der Atmospharischer Staub, VEP Deutscher Verlag der Wissenschaften, 1958.

C. E. Jungle, Air Chemistry and Radioactivity, Academic Press, New York, 1963

P. L. Magill, F. R. Holden and C. Ackley, Air Pollution Handbook, McGraw-Hill, New York 1956.

R. Meldau, Handbuch der Staubtechnik, Vols. I and II, V.D.I. Verlag, Dusseldorf, 1965 and 1958.

A. C. Stern (Ed.), Air Pollution, Academic Press, New York, Vols. I, II, III, (1968).

M. W. Thring, Air Pollution, Butterworth, London, 1957

American Industrial Hygiene Association: Air Pollution Manual, Vol. I: Evaluation, 1960, II Control Equipment, 1968.

B. Stoces and H. Jung, Staub und Silikosebe-kampfung im Bergbau, Akademie-Verlag, Berlin, 1962.

W. Ordinanz, Staub im Betrieb, Hauser, Munich, 1958.

D. H. Slade (Ed), Meteorology and Atomic Energy - 1968, USAEC Div. of Tech. Information (July 1968).

M. Smith, Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, ASME, NY, 1968.

R. S. Scorer, Natural Aerodynamics, Pergamon, 1958.

J.C. Johnson, Physical Meteorology, Wiley, 1960.

O.G. Sutton, The Challenge of the Atmosphere, Harper, 1961.

W.I. Humphreys, Physics of the Air, (1940 republished 1964), Dover.

Compendium of Meteorology, American Meteorological Society, Boston, Massachusetts, 1951, Outstandingly good.

Other texts of interest for specific technical aspects included:

T. Hatch and P. Gross, *Pulmonary Deposition and Retention of Inhaled Aerosols*, Academic Press, New York, 1964.

P. F. Holt, *Pneumoconiosis*, Arnold, London, 1957.

D. Birchon, *Optical Microscope Technique*, Newnes, London, 1961.

E. M. Chamot and C. W. Mason, *Handbook of Chemical Microscopy*, Wiley, 1958.

C. H. Needham, *Practical Use of the Microscope*, Thomas, Springfield, Ill., 1958.

L. C. Martin & B. K. Johnson, *Particle Microscopy*, Blackie, London, 1957.

A. H. Shapiro, *Shape and Flow*, Anchor paperback, 1961. Readable background on airflow past obstacles and boundaries.

C. Orr, *Between Earth and Space*, Collier paperback, 1961, The Atmosphere.

M. Minnaert, *Light and Color in the Open Air*, Dover paperback, 1961, readable background on light-scattering.

T. Allen, *Particle Size Measurement*, Chapman and Hale, Ltd., London, 1968.

H. E. Rose, *The Measurement of Particle Size in Very Fine Powders*, Constable & Co., London, 1958.

W. E. Kuhn, *Ultrafine Particles*, Wiley, New York, 1963.

A. W. Adamson, *Physical Chemistry of Surfaces*, Interscience Publ. New York, 1st Ed., 1960, 2nd Ed. 1967.

A. W. Zimon, *Adhesion of Dust and Powder*, Plenum Press, New York, 1969.

B. R. Fish, Ed., *Surface Contamination*, Pergamon, 1967.

V. G. Levich, *Physicochemical Hydrodynamics*, Prentice-Hall, Inc., Prentice-Hall, Inc, New Jersey, 1962.

J. Happel and H. Brenner, *Low Reynolds Number Hydrodynamics*, Prentice-Hall Inc., New Jersey, 1965.

L. Prandtr, *Essentials of Fluid Dynamics*, Hafner Publ. Co., New York, 1952.

M. Van Dyke, *Perturbation Methods in Fluid Mechanics*, Academic Press, New York, 1964.

C. Orr, Jr., *Particulate Technology*, Macmillan, 1966.

Control of Aerosol Particles

Technical accounts of aerosol suppression, filtration and control of industrial and urban air pollution are generally of limited scope. Much information is contained in Chapters in the books by Drinker and Hatch, Magill, Stern, Stoces and Jung, Meldau, and Ordinanz listed above; also in the following:

S. K. Friedlander, et al, Air Cleaning Handbook, US AEC, 1951.

R. Jorgensen (ed.), Fan Engineering, 6th Edition, 1961, Ch. 23, p. 549-590, Buffalo Forge Company, Buffalo, New York. A useful outline of air cleaning.

J. H. Perry (ed), Chemical Engineers Handbook, 3rd edition 1951, Dust and Mist Collection, Concise and authoritative with many references. The presentation of this subject in a recent edition of the Handbook is less detailed.

The following texts treat specific aspects of the subject in greater detail:

K. Rietema and C. G. Verver, Eds., Cyclones in Industry, Elsevier Pub. Co., Amsterdam, 1961.

P. A. F. White and S. E. Smith, High-Efficiency Air Filtration, Butterworths, London, 1964.

G. Nonhebel, Ed., Gas Purification Processes, G. Newnes, Ltd. London, 1964.

W. Strauss, Ed., Air Pollution, Wiley, 1970

W. Strauss, Industrial Gas Cleaning, Pergamon, 1966.

H. E. Rose and A. J. Wood, An Introduction to Electrostatic Precipitation Theory and Practice, 2nd Ed., Constable, London 1968; also see H. J. White's text cited previously.

J. A. Danielson, Ed., Air Pollution Engineering Manual, USDEW National Air Pollution Control Administration, PHS Publication No. 999-AP-40, 1967. (Presents information on air and gas cleaning and particulate control equipment for many typical applications).

Conferences on Aerosols

Conferences and meetings wholly or partly devoted to some aspect of aerosol science or technology are fairly frequent especially in the U.S.A. and in Germany. What is original is eventually published in the normal way. A few major international conferences have, however, produced volumes of proceedings which contain valuable original material, or are of historical interest as a record of the emphasis and interests at different stages in the progress of aerosol science. There are:

The Physics of Particle-Size Analysis, Brit. J. Appl. Phys., Suppl. No. 3 (1954).

Particle Size Analysis, Trans. Inst. Chem. Engrs. (London), Suppl. to Volume 25 (1947).

The Physical Chemistry of Aerosols, Discussions Faraday Sco. No. 30 (1960).

C. N. Davies (Ed.), Inhaled Particles and Vapours, Pergamon, Oxford 1961, Vol. I; Cambridge 1966, Vol. II; Vol. III, 1970.

M. Kerker (Ed.) Electromagnetic Scattering, Pergamon, Oxford, 1963

K. Spurny, (Ed.), Aerosols, Publishing House of the Czechoslovak Academy of Sciences, 1965.

Unfortunately proceedings of many conferences do not receive wide distribution, e.g., Physics of Aerosols, Condensation Nuclei, USAEC Air Cleaning Conference, etc.

Periodicals on Aerosols

Many fundamental studies on aerosols are published in the Journal of Colloid IF Science, Kolloid Zeitschrift, Colloid Journal (English translation from the Russian), International Journal of Aerosol Science, or in journals devoted to fundamental scientific disciplines such as optics, physical chemistry, fluid mechanics, and atmospheric physics. The papers in the journal Staub (= dust) are as variable in subject matter as in quality, the majority being empirical and technological, but its abstracts section is excellent and unequalled in its coverage. Staub appears in English as well as in the German edition. Many papers on aerosols are included in Chemical Abstracts but are not always indexed as such. Journals concerned with air pollution, industrial hygiene, mining, fuel technology, meteorology, applied optics, chemical engineering science, powder technology and others also carry papers on aerosols.

Classification of Aerosol Literature

There have been relatively few efforts directed to a complete classification of aerosol literature. Strehlow[1] and Scheffy[2] prepared annotated bibliographies on aerosols for the USAEC in 1950 and 1958, respectively. Their acquisitions on meteorology and air pollution were restricted in scope (independently estimated from a comprehensive bibliography[3] in 1954 at 3900 air pollution items). They list 1936 (Ref. 2) and 947 (Ref 3) items on aerosols up to 1955. No comprehensive bibliography on aerosols has been published since 1955. The number of articles and books produced in recent years indicates that the total amount of information available is substantially greater than at that time. Fuchs[4], who has proposed a classification system for aerosol literature, suggests there may be in excess of 20,000 source documents available dealing with aerosols. This figure is probably low. No single source has been located having a complete retrievable holding.

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APPENDIX 2.3

COMPACTION EFFECTS IN GRANULAR MEDIA*

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*(From a manuscript released by I.M. Kolthoff and I. Shapiro in December, 1962 for publication as an ASD Technical Documentary Report. Authors are believed to have been associated with Battelle Memorial Institute, Columbus, Ohio.)

A. Retrospection

The techniques of compounding and fabricating materials from powder form is widely utilized in a number of industries, but the study of the underlying principles relating void content of powders with pressure has been comparatively neglected. A literature survey on the compressibility of powders reveals isolated attempts to make such studies, but, because of limited scope and objectivity, such studies usually degenerated to the formulation of empirical relationships of compressibility with pressure. The applicability of these relationships has been found to be very limited, hence the need for a systematic study of the compressibility of particulate matter directed towards predicting properties of compacts as function of pressure.

The objective of the program reported here was to examine a broad spectrum of materials ranging in properties from "plastic" to "brittle" and determine their compressibilities at ambient temperature. In order to make comparisons of the compaction behavior of the various powders, it was first necessary to set certain restrictions so as to reduce the number of variables that would be encountered. Based on past experience, two restrictions were deemed necessary here. First, the particles must be of fairly uniform size; mixed sizes will greatly influence the packing of particles. The "uniform size" refers both to particles within a sample and to particles of different powders. Second, in compressing the particles within a die, the ratio of depth of compact to diameter of compact must be kept to a minimum value (consistent with experimental measurements) in order to avoid die-wall frictional forces. These two restrictions are mentioned here so that when one reads the historical background on compression of powders, one will appreciate how variables can be introduced without awareness on the part of the experimenter. Only by isolating the variables can one make a reasonable attempt to study the compaction behavior of various powders. Unfortunately, in many of the previous studies such precautions were not always taken; consequently, one must view published data with a certain degree of suspicion.

B. Literature Review

A compendium of references to the literature on Powder Metallurgy to 1950 is given by C. G. Goetzel.(1) It is interesting to note that of the many thousands of references only a handful refer to studies trying to elucidate the compaction behavior of powders. By far the greatest effort is found in the field of Metallurgy; in the field of Pharmacy where the tableting of pills is important, the effort has been practically nil. Interest in the field of Ceramics is starting to be generated.

Prior to 1940, the effort devoted to the study of the principles of powder compressibility was exceedingly small. Dr. W. D. Jones wrote the first prewar book(2) on the principles of powder metallurgy in 1937. Bal'shin(3) presented his theory on the compaction of powders by applying the concept of fluid mechanics.

In the decade 1940-1950, there was a flurry of activity in the field with a number of articles, monographs, and symposia being published -- a great number of them related to the sintering phenomenon. J. Wulff(4) edited the papers presented at the 1940 and 1941 Conferences on Powder Metallurgy (held at M. I. T., Cambridge). At that time, the discussions on principles of powder compaction were pretty sketchy. At the symposium held at Bayside, L. I., New York, in August 1949 (articles edited by W. E. Kingston(5)), a paper presented by R. P. Seelig gave a good account of the theories and concepts on the fundamentals of pressing metal powders that had evolved during the decade. During this period, several text-type books were authored by Kieffer and Hotop, (6, 7) Hausner, (8) and Goetzel(9). The latter discusses the theories advanced by Bal'shin, (3) Unckel, (10) Seelig and Wulff, (11) and Kamm, Steinberg, and Wulff(12). Equations relating the porosity or density of compacted powders with pressure were presented by Shapiro, (13, 14) Smith, (15) and Konopicky(16).

After 1950, the activity was sporadic with only a few papers devoted to compaction phenomena appearing in the literature. A perusal of the papers presented at the International Powder Metallurgy Conference, (17) New York, 1960, showed little advancement in the state of the art of cold (ambient temperature) compaction -- the concentration of effort being on sintering and hot-pressing. The best review of pressing of powders to date is given by W. D. Jones (18) in his text on Fundamental Principles of Powder Metallurgy (1960). More recent articles dealing with this subject will be presented with the detailed discussions in this report.

C. Background on Powder Compressibility

The compression of a loose powder in a die to form a coherent mass is the foundation of powder metallurgy and ceramics. A number of theories have evolved on the mechanism of compacting and the bonding forces holding the compact together.

Seelig and Wulff(11) consider the compaction process of powdered metals as consisting of three steps: (1) packing, (2) elastic and plastic deformation, and (3) cold-working (with or without fragmentation). The authors stress that the three steps do not follow each other in sequence, but may overlap each other, and at least one of them may be absent under many conditions; e. g., with powders such as lead and tin, steps one and three are of little significance, while with hard powders such as chromium or tungsten carbide, step two is practically absent. In summary, the significance of any of the three steps depends to a large extent on the plasticity of the powder used.

In his review of the literature on pressing of metal powders, Seelig(19) summarizes the experimental work on the importance of die-wall friction with the density distribution in a compact. In the case of long compacts, i.e., high length to diameter ratio, the die-wall friction may be very appreciable, so that from the standpoint of studying the compaction of powders it is necessary to separate these frictional forces from other forces in the compact.

The effect of lubricants on nickel powder compacts also was studied(11). The conclusion drawn was that die-wall friction was far greater than inter-particle friction.

The bonding forces holding a compact together by cold pressing are attributed to one or more of the following phenomena:(19) Attractive forces (atomic), mechanical inter-locking, electrostatic forces, cold welding, local melting, and vacuum created by expelling gases from the pores. Although the measurement of bonding forces (by strength of compacts) is beyond the scope of work described in this report, the results of the work do shed some light on several of the possible bonding forces.

In the field of Ceramics there is a certain amount of parallelism to Powder Metallurgy in the compression of powders. In both fields the problem is to achieve a coherent compact which can be handled -- usually for further treatment such as sintering or firing. The principal difference between metals and ceramics is the physical characteristics of the powder -- though in some instances, this difference is not too sharply defined. In an article on the role of powder density in dry-pressed ceramic parts, Berry, Allen, and Hassett(20) report that the total compaction of a pelleted ceramic takes place in three principal stages: (1) formation of granules, (2) pressing, and (3) firing. Although the first stage often is considered to be independent of the others, these authors show that the properties of the powder exert a major controlling influence on pressing and firing behavior. An interesting conclusion of these authors is cited: "In conclusion, we wish to restate the rather surprising fact that granular powders may contain as much as 70% voids and only 30% solids. Therefore, if ultimate density is desired in a ceramic body, the fundamentals of packing, void distribution, and compaction must be understood and applied." More recently, Cooper and Eaton(21) have studied the compaction behavior of four ceramic powders of widely different hardness, but of essentially the same particle-size fraction. These authors have attempted to explain the compaction process as a combination of two processes, one caused by rearrangement of particles, or the filling of large voids, and the second process by fragmentation (with or without plastic flow), or filling of small voids. The concept of particles sliding past one another also is widely believed in powder metallurgy circles.(18) Current findings described in the experimental portion of this report reveals that this concept may be incorrect.

D. Conclusions and Summary of Theoretical and Experimental Program

Compressibility of powders takes place via plastic deformation, such as in the case of magnesium, or via fragmentation, such as in the case of thoria, or via a combination of the two types, such as in the case of molybdenum disulfide.

For plastic materials the effect of pressure, p, on the porosity, P, of a packing of powder whose initial bulked porosity is P_o, can be expressed by the Shapiro-Konopicky Equation

$$P = P_o e^{-k_i p}$$

For other materials two terms of the general equation

$$P = \sum_i a_i e^{-k_i p}$$

are required. One term whose influence is in the low-pressure range is believed to be related to the porosity of the individual particles.

The initial or bulked porosity, P_o, is a function of particle size and size distribution, particle shape, and porosity of the individual particle.

Photomicrographs taken during the compression process reveal that particles do not slide past one another during compaction, regardless of the type of compaction, i.e., plastic deformation or fragmentation. The same mechanism applies in filling large holes or small pores in any one system.

For unrestricted compression of an individual magnesium sphere the ratio of load to bearing surface is a constant. For restricted compression, such as in the case of a monolayer or polylayer of magnesium spheres, greater loads can be sustained than for a single sphere of the same bearing surface area.

When two curved surfaces of the same plastic material are compressed together, the intersection of the two surfaces is a "flat" plane, thus the concept of purely mechanical interlocking of particles as an explanation of cohesion of a pressed pellet does not appear valid.

Fragmentation of ceramic-type particles result in formation of many fine fragments as well as several large fragments. The concept of fine fragments falling away from the bearing surface in the initial stages of compression may account for the changing slope of the logarithm porosity-pressure curve.

Compression of mixed powders results in the type of compression basic to the single powders. In the case of mixtures of molybdenum disulfide with ceramics, such as thoria or silica, the molybdenum disulfide can "flow" around the ceramic particles.

The recompression effect observed for silica and its mixtures is appreciable, may be related to the elasticity of the powder, and must be taken into account in applying compressibility equations.

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APPENDIX 2.4

SPECIFICATIONS FOR SELECTED FILTER FABRICS

Some of the principal specifications for selected fabrics from two fabric manufacturers are tabulated. These specifications are standards, and some variation may be expected. When desired, other designs may also be available.

TABLE 2.4(a)

STANDARD SPECIFICATIONS FOR FILTER FABRICS*

Style No.	Fiber Material	Air flow (Gurley) Permeability cfm/ft^2 at 1/2 in. H_2O	Mullen Burst, psi	Weight oz./sq.yd.	Count	Weave	Finish
1210	Cotton	15-20	310	9.7	96x60	Sateen	Plain
1215	Cotton	10-15	240	9.7	96x58	Sateen	Siliconized
1216	Cotton	5-10	230	9.7	96x60	Sateen	Flameproof
1217	Cotton	15-20	300	9.7	96x60	Sateen	Napped
1226	Cotton	35-40	200	8.2	64x40	-	Napped Canton flannel
1227	Cotton	45-50	260	10.4	64x35	-	Napped Canton flannel
1228	Cotton	15-20	280	11.9	60x36	-	Napped Canton flannel
1400	Orlon^R Acrylic	25-30	255	6	78x68	3x2 twill	Scoured, heat set, calendered
1417	Orlon^R Acrylic	55-60	275	11	39x29	Woolen system 2x2 twill	Heat set, homopolymer
1418	Orlon^R Acrylic	35-40	315	11.7	38x36	Woolen system 2x2 twill	Heat set, homopolymer
1460	Orlon^R Acrylic	25-30	255	14-16	-	Felt	Heat set, spun acrylic grid

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*Industrial Filter Fabrics, Engineered Fabrics Corp., Division of Schwartz Manufacturing Co., Two Rivers, Wisconsin, 1969.

TABLE 2.4a (Continued)

Style No.	Fiber Material	Air flow (Gurley) Permeability cfm/ft^2 at 1/2 in. H_2O	Mullen Burst, psi	Weight oz./sq.yd.	Count	Weave	Finish
1506	Nylon	3-5	740	6.5	56x44	Plain sateen,	
1513	Nylon	25-30	635	7.3	96x71	filament warp, spun fin	
158	Nomex^R	35-40	525	14	-	Felt	Spun Nomex^R grid
1613	Fiberglass	15-20	605	8.5	54x42	Crow foot	Siliconed graphite 150's 1/2 warp & fill
1614	Fiberglass	55-60	465	12	43x30	3x1 twill	Siliconed graphite, 150's 2/2 warp, bulked 1/4 fill
1616	Fiberglass	45-50	595	16	48x22	2x2 broken twill	Siliconed graphite, 150's 2/2 warp, bulked 2/2 fill
1750	Wool	40-45	185	12-14	-	Felt	Plain
1753	Wool	25-30	255	16-17	-	Felt	Plain
1754	Wool	30-35	255	16-17	-	Felt	Silicone
1756	Wool	30-35	270	18-19	-	Felt	Plain
1758	Wool	15-20	270	18-19	-	Felt	Flameproof
1803	Polypropylene	30-35	450	4.5	75x69	Twill	Scoured, heat set

TABLE 2.4a (Continued)

Style No.	Fiber Material	Air flow (Gurley) Permeability cfm/ft^2 at 1/2 in. H_2O	Mullen Burst, psi	Weight oz./sq.yd.	Count	Weave	Finish
1850	Polypropylene	25-30	860	17-18	-	Felt	Dacron^R grid
1851	Polypropylene	35-40	740	11-12	-	Felt	Poly. grid
1900	Polyester Dacron^R ,Vycron^R	15-20	530	5.4	77x68	3x1 twill	Scoured, heat set, calendered
1905	Dacron^R, Vycron^R	40-45	690	12.7	40x32	Woolen system 2x2 twill	Scoured, heat set, siliconed
1915	Polyester Dacron^R, Vycron^R	12-20	430	4.8	76x68	3x1 twill	Scoured, heat set, siliconed
1950	Polyester (Dacron^R)	10-15	575	18.5	-	Felt	Heat set, unsupported
1952	Polyester (Dacron^R)	25-30	355	11-12	-	Felt	Heat set, Dacron^R grid
1953	Polyester (Dacron^R)	40-45	365	11-12	-	Felt	Heat set, siliconed, Dacron^R grid
1954	Polyester (Dacron^R)	15-20	680	16-17	-	Felt	Heat set, Dacron^R grid
1955	Polyester (Dacron^R)	15-20	680	16-17	-	Felt	Heat set, siliconed, Dacron^R grid
1962	Polyester (Dacron^R)	30-35	392	15	-	Felt	Heat set, Dacron^R grid
1964	Polyester (Dacron^R)	25-30	392	15	-	Felt	Glazed 1 side, heat set, Dacron^R grid

TABLE 2.4b

STANDARD STYLES AND SPECIFICATIONS FOR FILTER FABRICS*

Style No.	Designed for Fabric Cleaning Method	Weight Oz/Sq. Yd.	Weave	Count	Air flow (Frazier) Permeability CFM/FT^2 at 1/2 in. H_2O	Fiber
862B	Sh	10	Plain	30x28	55	Dacron^R polyester
C866B	Sh	12	2 AST	38x37	40	Dacron^R polyester
C868B	Sh	12	2x2 Twill	40x39	32	Dacron^R polyester
C890B	RA	5	3x1 Twill	F72xF67	25	Dacron^R polyester
C892B	RA	5	3x1 Twill	F66xF56	12	Dacron^R polyester
865B	Sh&RA	10	1x3 Crow Foot	F71x51	33	Dacron^R polyester
136B	RJ	18	Needled	--	35	Dacron^R polyester
137B	RJ	11	Needled	--	70	Dacron^R polyester
810L	Sh	10	2x2 Twill	38x33	60	Microtain^R acrylonitrile
811L	Sh	10	2 AST	39x37	37	Microtain^R acrylonitrile
812B	RA	4	3x1 Twill	F79xF70	28	Microtain^R acrylonitrile
150B	RJ	15	Needled	--	37	Microtain^R acrylonitrile
802B	Sh	11	2x2 Twill	34x36	42	Nylon polyamide
895	Sh	10	Plain	26x21	150	Wool/Dacron^R polyester
960	Sh	10	Satin	95x58	13	Cotton
723	Sh	10	2 AST	35x37	32	Polytain^R olefin
165	RJ	12	Needled	--	50	Polytain^R olefin
852	Sh	8	Plain	29x26	60	Nomex^R aromatic nylon
853	Sh	10	2x2 Twill	40x37	32	Nomex^R aromatic nylon
850	RA	4.5	3x1 Twill	F98xF79	18	Nomex^R aromatic nylon
190	RJ	14	Needled	--	40	Nomex^R aromatic nylon
Q53-870	--	9	C.F.	F55xF52	14	Glass
Q53-874	--	16.5	2x2 Twill	F48xS22	55	Glass
Q53-875	--	9	3x1 Twill	55x52	52	Glass
Q53-878	--	14	3x1 Twill	F46xT24	55	Glass

Note: F = filament T = texturized S = spun Sh = shaker type cleaning
RA = reverse air RJ = reverse jet

*from Dry Filtration Manual, Albany Felt Co., Industrial Fabrics Division, Albany, New York, 1969.

APPENDIX 2.5

SPECIFIC DUST-FABRIC FILTER RESISTANCE COEFFICIENTS

The following table lists specific resistance data available from the fabric filtration literature, together with several parameters believed to contribute to the determination of the specific resistance. Usually the original reference provides additional insight into the variations of specific resistance.

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SPECIFIC DUST-FABRIC FILTER RESISTANCE COEFFICIENTS

Ref.*	Dust Characteristics		Cloth Characteristics					Filtering Velocity, FPM	Specific Resistance, K_2' (2)
	Type	Size, μm	Type	Clean Perm. (1)	Weight oz.	Yarn Type	Threads per in.		
127	Fly ash	20, ave.	Glass					2.3	7.0
	Fly ash		Glass					3.5	12.0
	Fly ash		Cotton					2.3	4.3
	Fly ash		Cotton					3.5	7.8
	Stone dusts								2-13
	Stone dusts								4-6
148	Cement dust	Coarse (100)	?					3.0	6.1
	Cement dust	Fine(20)						3.0	7.6
	Limestone	Coarse						3.0	9.7
	Limestone	Fine						3.0	14.1
149	Fly ash	10, ave.	Nomex^R Fil.	17.5	4.5	Cont. Fil.	87	4.0	11.5
	Fly ash		Polypro.	15	4.3	Cont. Fil.	73	4.0	6.2
	Fly ash		Nomex^R	22.5	5.4	Fil. Spun	76	4.0	7.8
	Fly ash		Teflon^R	30	8.6	Cont. Fil.	69	4.0	8.7
	Fly ash		Cotton Sateen	17.5	9.5	Spun	80	4.0	5.8
	Fly Ash		Dacron^R	25	5.77	Fil. Spun	79	4.0	7.7
	Fly Ash		Spun Orlon^R	20	5.7	Spun	81	4.0	5.8
	Fly Ash		Spun Acrylic	60	9.8	Spun	37	4.0	5.8

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*For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. H_2O/(lb/ft^2 - FPM).

(continued)

Ref.*	Dust Characteristics		Cloth Characteristics					Filtering Velocity, FPM	Specific Resistance, K_2(2)
	Type	Size, μm	Type	Clean Perm. (1)	Weight oz.	Yarn Type	Threads per in.		
126	AC Test Dust	5-10, ave.	Nomex^R	18	4.6			5/20	2.0/2.6
	"		Acrylic	31	4.4			5/20	0/3.4
	"		Acrylic	24	4.4			5/20	2.9/2.3
	"		Acrylic	19	3.8			5/20	2.1/9.2
	"		Acrylic	10	3.9			5/15	16.5/13.5
	"		Acrylic	29	5.7			5/20	1.0/1.3
	"		Olefin	13	4.3			5/20	1.5/5.2
	"		Nylon	26	3.4			5/20	5.0/14.5
	"		Polyester	26	6.0			5/20	1.2/2.1
	"		Polyester	37	3.1			5/20	1.5/1.9
	"		Polyester	1.6	3.3			5/--	22.6/?
	"		Polyester	75.5	4.25			5/20	0/1.1
	"		Polyester	24.5	4.50			5/20	3.1/5.0
	"		Polyester	17	5.85			5/20	2.0/2.1
	"		Polyester	70	4.51			5/20	0.6/1.9
150	Petroleum			New/Used					
	Coke	(Med. Surface	Orlon^R	35/10	3.9			~3.4±	17.1
	"	Cloth)	Orlon^R	85/58	7.6	Napped filament, 3/1 twill		~3.4±	12.5
	"		Orlon^R	60/33	7.5	Knit, napped		~3.4±	15.0
	"	(Hi Surface)	Orlon^R	100/50	9.0	Spun staple		~3.4±	7.4
	"	"	Orlon^R	110/62	4.9	Spun staple, napped 2s		~3.4±	13.0
	"	(Low Surface)	Fiberglass			Spun fiberstock 3/2 twill		3.6	29.8
	Fresh MgO	Napped side	Orlon^R	35?/4.2	4 oz.	Napped filament, 3/1 twill		?	234.0
	Fresh MgO	Unnapped sd.	Orlon^R	35?/8.1	4 oz.	Napped filament, 3/1 twill		?	254.0
	Steel paint drums, abrasive blasted	"Very fine dust"	Orlon^R			Hi twist-unnapped		3.60	29.2
			Orlon^R			Fiberstock-unnapped		3.55	14.8
	Silica Gel	43%<10μ	"std" cotton sateen cloth					3.82	57.4
	Gnd limestone	32%<44μ	"std" cotton sateen cloth					2.90	0.43
	Steel paint Drums etc.	2%<10μ	"std" cotton sateen cloth					3.78	5.3

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*For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. H_2O/(lb/ft^2 - FPM)

(continued)

Ref.*	Dust Characteristics		Cloth Characteristics					Filtering Velocity, FPM	Specific Resistance, K_2'(2)
	Type	Size, μm	Type	Clean Perm. (1)	Weight oz.	Yarn Type	Threads per in.		
152	Quartz pwdr	72%<10μ 100%<25μ	Wool 510	61	11.4			120	1.55
			Wool 410	68	13.3			120	0.97
			Wool 610	22	14.5			120	1.50
			Wool 650	38	15.2			120	1.89
		72%<10μ 100%<25μ	Polyacrylinitrile 360S	40	8.0			120	3.8
			" 360R	42	8.1			120	3.8
			" 410S	60	9.1			120	4.1
			" 410R	55	9.2			120	1.6
			" 376S	36	10.3			120	3.4
			" 376R	38	10.3			120	1.6
		72%<10μ 100%<25μ	Glass	9.7	10.3			120	7.1
		72%<10μ 100%<25μ	Mesh	64				120	14.0
153	Quartz pwdr		Nessel 1	62	5.4			120	0.50
			Nessel 9S	14.5	13.7			120	2.0
			Nessel 9R	23	13.7			120	1.2
			Wool 51	59	11.7			120	1.2
			Wool 65	41	14.9			120	1.8
			PAN 36S	53	7.7			120	2.0
			PAN 76S	38	10.0			120	2.1
			PAN 36R	45	8.2			120	0.3
			PAN 76R	35	10.5			120	1.3
			"Lace" 30	65	45			120	1.3

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*For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. $H_2O/(lb/ft^2 - FPM)$

(continued)

Ref.*	Dust Characteristics		Cloth Characteristics					Filtering Velocity,FPM	Specific Resistance,K_2'(2)
	Type	Size,μm	Type	Clean Perm.(1)	Weight oz.	Yarn Type	Threads per in.		
82	Ground Mica	5-10μdia. 0.5μ thick	Fiber- glass #3	7.86	9.06	3/1 Crow ft.	55x58	2.0	15.3
	Ground Mica	5-10μdia. 0.5μ thick	Fiber- glass #1	13.4	8.41	3/1 Crow ft.	55x50	2.0	24.2
	Ground Mica	5-10μdia. 0.5μ thick	1&3 aver.	(ave)				6.0	19.3
	Ground Mica	5-10μdia. 0.5μ thick	"	"				4.0	8.8
	Ground Mica	5-10μdia. 0.5μ thick	"	"				2.0	3.5
	Ground Mica	5-10μdia. 0.5μ thick	Dacron^{R}A	28.1	5.5	3/1 Twill	82x62	2	21.5
	Ground Mica	5-10μ dia. 0.5μ thick	Dacron^{R}B	14.6	6.1	3/1 Twill	82x76	2	15.1
154	Carbon Blk	Sub. m.	Orlon^{R}			Napped		2.8	20,000
	FeOx	Sub. m.	Orlon^{R}			Napped		2.54	2600-3100
	FeOx	Sub. m.	Orlon^{R}			Napped		2.54	69-84
118	A.C. Fine	5μ ave.	Cotton	6.4		Sateen, heavy		3.34	62.3
	A.C. Course	30μ ave.	Cotton	6.4		Sateen, heavy		5.33	27.1
	Fly Ash	15μ ave.	Cotton	6.4		Sateen, heavy		5.33	38.0
155	Cu Smelter (Zn,Pb,...)		Glass (pilot)					2-3	300
	"		Glass (full scale)	58,76	12.5	1-3Twill	36x34,36x32	1.57	37.

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*For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. H_2O/(lb/ft^2 - FPM)

(continued)

Ref[*]	Dust Characteristics		Cloth Characteristics					Filtering Velocity, FPM	Specific Resistance, K_2'(2)
	Type	Size, μm	Type	Clean Perm. (1)	Weight oz.	Yarn Type	Threads per in.		
156	Fly Ash		S.S.Porous						
			Disk C	18.2			Pore Mean 165μ	18.5	Low Eff.
			" D	7.3			Pore Mean 65μ	18.5	5.75
			" E	1.			Pore Mean 35μ	18.5	5.75
157	El. Fnce (Steel)	70%<5μ	Orlon^R					(3.)	(32)
158	Electric								
	Steel Fnce.		Polyester#0410			Low Surf. Area		(2.5)	37.8
	"		Acrylic#0701			Med. Surf. Area		(2.5)	19-64
	"		Acrylic#0714			High Surf. Area		(4.)	12-30
159	Atoms.		New Cotton					(1.7)	~135.
	Talc(Nytal)	(Load Var.)	Cotton			(Sateen?)		3.	27-46
	Fly Ash		Cotton			Sateen(?)		8.4	44
	Fly Ash		Heavy Wool Felt					7.6	63
	Fly Ash		Lt.Wool Felt					6.5	77
	Fly Ash		Orlon^R					13.0	17
160	Real Fly Ash	(15μ?)	Glass					2.26	10
	"		Glass					2.26	7.6
	"		Glass					(3.15)	12
	"(&limestone)		Glass					(3.15)	16
	"		Glass					(3.15)	16
	Lab Fly Ash		Glass					2.26	4.2 (Analysis)

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[*] For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. H_2O/(lb/ft^2 - FPM).

(continued)

Ref.*	Dust Characteristics		Cloth Characteristics						
	Type	Size, µm	Type	Clean Perm. (1)	Weight oz.	Yarn Type	Threads per in.	Filtering Velocity, FPM	Specific Resistance, K_2' (2)
161	NH_4Cl		A Cotton	20	17.3	Full	29x28	5-10	(57.)
			B Cotton	21	11.9	Details &	39x31	5-10	(6.5)
			C Cotton	19	13.0	Discussion*	44x20	5-10	(11.0)
162	Ground							6	42.6 x A
	PVC							3.7	11.4 x A
163			(3) →						
164			Fiber grids only					Extreme Hi	
165	Fly Ash		Woolen					10	.3-.77
166	Fly Ash and Limestone	10-20µ Ash ~50µ Lime Ave: 33.6µ	Glass	75	10	3x1 Twill		2.32	16.9
		41.3µ	Glass	75	10	54x30		2.32	7.4
		37.5µ	Glass	75	10	54x30		2.32	11.3
		36µ Ave.		75				2.32	15.7
		(47) µ		75				3.46	18.0
		34µ		75				3.46	25.8
		34µ		75				2.32	16.9
		30µ		75				1.86	5.0
167	Crushed Rock, Ore		Terelyene^R Polyester	Napped Flannel				7.	1.92
	"		"	"				(7)	12.7
	"		"	"				(11)	7.2

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*For references. see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. H_2O/(lb/ft^2 - FPM).

(continued)

	Dust Characteristics		Cloth Characteristics						
Ref.*	Type	Size,μm	Type	Clean Perm.(1)	Weight oz.	Yarn Type	Threads per in.	Filtering Velocity,FPM	Specific Resistance,K_2'(2)
168	Stone Crushing								2.7 Ave.
	"								
	"								
	Foundry misc.								7.6 Ave.
	Stone Chiseling							(3-4)	3.2
169	Lead		Woolen			"Plain"		1.95	197
	"D&L"							1.45	106.
	Smoke							.91	139.
								.57	110
								1.4	61.5
								1.0	133
								.71	112
								.5	101
170	Foundry	~50μ	Glass wool (1952)					2.7	8.9
	Hydrated Lime Transp.	~15μ	Cotton					3-5	0.83
128	Fly Ash	3.2μ							
		(<7μ)	Cotton	15	9	Sateen	96x60	(0.7)	2.4
		"							7.1
		"							10.4
		"							12.7

*For references, see Volume 1, Chapter 2.

(1) Permeability, CFM/ft^2 at 0.5 in. H_2O

(2) Resistance, In. $H_2O/(lb/ft^2 - FPM)$.

APPENDIX 2.6

EFFECTS OF FABRIC SURFACE ON DUST DEPOSIT

Additional indication of the effect of surface nap in opening the structure of the deposited dust and in lowering the flow resistance of the deposit has been given by Kimura and Iinoya* in Figures 2.5 a, b. In these figures the effect of velocity is not extractable, although velocity is stated to have been varied ten-fold in the experiments. The type of dust used was not stated, nor were the fabrics identified. The data were not identified as being from a fabric filter operating at equilibrium.

Figure 2.5a indicates that at ~1 percent dust accumulation the permeability of the accumulated layer is low and increasing with added accumulation. A maximum permeability is reached near ~10 percent dust accumulation. With deep accumulation the permeability approaches a constant value. The reasons for these trends are not apparent and may reflect the particular aerosol used. More to be expected is the effect in Figure 2.5b of particle size on the porosity of the deposit: Small particles formed a more open structure.

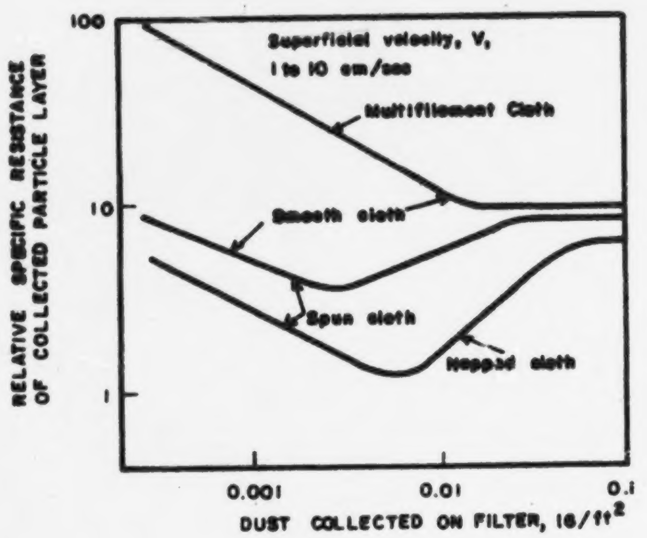

Figure 2.6a. Effect of the Fabric on the Average Specific Resistance of the Dust Layer.

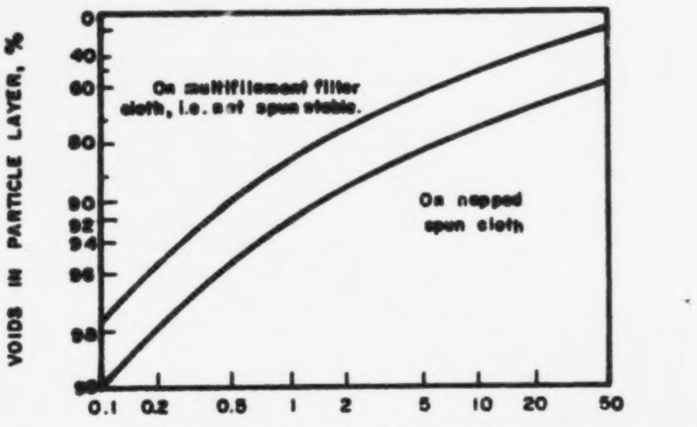

Figure 2.6b. Relation Between Specific Surface Diameter of Particles Collected and the Voids of the Collected Particle Layer.

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*N. Kimura and K. Iinoya, Chem. Eng. (Tokyo) 29, 166 (1965), cited in K. Iinoya and C. Orr, Jr., Source Control by Filtration in Air Pollution V. III, A.C. Stern, Ed., Ch. 44, p. 419, Academic Press, New York (1968)

APPENDIX 3.1

FABRIC FILTER MANUFACTURERS' SUMMARY, 1969

FABRIC FILTER MANUFACTURERS SUMMARY 1969

Manufacturer	Trade Name	Characteristics	Method of Cleaning
Ace-Sycamore, Inc. 448 Dekalb Avenue Sycamore, Illinois 60178		one bag cleaners, to 100 ft^2, several types	Manual
Aerodyne Machinery Corp. 6330 Industrial Drive Hopkins, Minnesota 55343		outside filtering, upward flow bags with twist-on support cages	
	Vibro Stream VS Series	625-18000 ft^2 and up Modular, multi-compartment, continuous.	Vibration at top plus forced reverse flow; pneumatic time
	Reverse Air Stream RAS Series	625-18000 ft^2 and up Modular, multi-compartment, continuous.	Reverse pulse; pneumatic timer.
	Super Jet Stream SJ Series	8-800 ft^2 Preassembled, continuous	Reverse pulse, 3-10CFM 100 psi; adjustable solid state timer.
	HPE	1400-18432 ft^2 and up modular, multi-compartment, continuous.	Reverse pulse and bag expansion. Adjustable solid state controls.
	RSI	Inside Filtering, upward flow bags; 2000 ft^2 and up. Continuous. (Glass bags.)	Reverse flow plus reverse pulse. Solid state controls
The Air Preheater Company A Sub. of Combustion Eng. Wellsville, New York 14891		Outside filtering, upward flow bags	
	Ray-Jet	450-3600 ft^2 in 15 sizes continuous, panel construction, diaphragm manometer.	Reverse pulse, automatic, adjustable timer
Aget Manufacturing Company 1408 E. Church Street Adrian, Michigan 49221		Upward flow bags;	
	Filter Kop FH Series	700-2800 ft^2, Modular One compartment, intermittent	Shake, manual or powered.
	FT Series	Inside filtering, up or downward flow bags; 120-383 ft^2 one compartment, intermittent	shake, manual or powered.
		Single-bag collectors, 100-1700 CFM	
		Hoppers and support stands.	

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
American Air Filter CO., Inc 215 Central Avenue Louisville, Kentucky 40208	Amerjet Model C	Inside filtering, downward flow tubes; 310-2390 ft^2 continuous, cylindrical	Reverse jet, choice of 2 carriage speeds.
	Amerpulse	Outside filtering, downward flow bags; 61-4400 ft^2 continuous, downflow of dirty air.	Reverse pulse, automatic, adjustable, 1 to 3 SCFM per 1000 CFM.
	Amertherm	Inside filtering, upward flow bags; 1320-9660 ft^2 continuous, cylindrical primarily with glass cloth	Reverse flow plus collapse Automatic
	Amertube	Inside filtering, upward flow bags; 1339-10,008 ft^2; intermittent. Manometer	Shake, timer.
	"	Also 1334-11,675 ft^2; continuous	Shake, timer, reverse flow option.
	Arrester	Envelope type 80 or 150 ft^2 per module Intermittent	Vibration, automatic
	Arrestall	Envelope type 30-180 ft^2 Intermittent.	Shake, manual
Bahnson Company 1001 South Marshall Street Winston-Salem, N. Carolina	Collecto-card	Inside filtering, tube Approximately 1000 ft^2; primarily for textile room use.	Shake, manual
Buell Engineering Co., Inc. Northern Blower Division 6409 Barberton Avenue Cleveland, Ohio 44102	Norblo - Automatic type --Series 39 --Series 54	Inside filtering, upward flow bags; Modular Continuous access 696 ft^2 and up, 480 and 936 ft^2 modules 1879 ft^2 and up, 1296 ft^2 modules	Vertical shake plus small reverse flow, by adjustable timer.

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	-Intermittent	Intermittent	Vertical shake, timer.
	--Series 6B	360, 720 ft^2	
	--Series 40	960 ft^2 and up	
	--Series 56	1344 ft^2 and up	
	-Portable	36-135 ft^2; intermittent.	Shake, manual
	--Series 6B	360, 720, 1080 ft^2	
	New-Cleaire	Intermittent; ultrafiltration via filter aid	Shake, usually during plant shutdown
	--Series 56-9	1512 ft^2 and up	
	-Shakerless	696 ft^2 and up; Modular Compartmented, continuous, Mainly for glass cloth	Reverse flow plus collapse. timer
Buffalo Forge Company 490 Broadway Buffalo, New York 14204		Inside filtering, downward flow tubes;	Reverse jet
	Aeroturn	405 ft^2 and up	
	-Type B	Modular; continuous access Also 90-225 ft^2 units.	
		Upward flow, inside filtering bags;	
	-Type S	628 ft^2 and up 314 and 628 ft^2 modules Intermittent; manometer	Shake, powered; manual initiation.
		Also continuous access, 1 to 4 compartments.	Same, or automatic.
Carter-Day Company 655 19th Avenue, N.E. Minneapolis, Minn. 55418	Day	Outside filtering, upward flow, oval envelopes	
	-CS Type	Oval envelopes, 58-1530 ft^2 Continuous; cylindrical	Reverse flow plus 80 psig sonic reverse pulse, continuous with timer option.
	-RJ Type	Outside filtering, upward flow, oval envelopes 58-1530 ft^2 continuous, cylindrical	Reverse flow with damper pulse.

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	-RT and RTR Type	Inside filtering, upward flow bags; 50-660 ft^2 Intermittent	Shaker
	-AC Type	Inside filtering, downward flow tubes; 50-1217 ft^2 Continuous	Blow-ring reverse jet
	Daynamic	Continuous	Reverse pulse plus reverse flow
		Fans, blowers, airlocks, conveyors custom system design	
Cincinnati Fan and Ventilator Co. 6521 Wiehe Road Cincinnati, Ohio 45237	Dust Master	Portable one-bag unit with cyclone, about 6 ft^2	Manual
R. F. Cox Associates Essex, Mass.		Inside filtering, upward flow; 300 ft^2 and up	Shake, powered, manual initiation
Dracco Division Fuller Company 124 Bridge Street Catasauqua Pa. 18032	Plenum Pulse	Outside filtering, upward flow bags; up to 500 ft^2 per module compartmented, continuous cylindrical or regular	Reverse pulse, adjustable timer.
	Uni-Filter	Upward flow bags; (vacuum type) 100-600 ft^2	Shaker, with isolation
	Mark II	Inside filtering, upward flow bags; 720 ft^2 and up compartmented	Shaker, powered, with isolation
	Glass Cloth	Inside filtering, upward flow bags or downward flow tubes; 80-180 ft^2 per bag; compartmented	Reverse air collapse with isolation; sonic cleaning; adjustable timer.
	Retro Pulse	Inside filtering, upward flow bags; (vacuum type): 1000, 2000 ft^2 modules	Reverse air collapse with isolation

FABRIC FILTER MANUFACTURERS SUMMARY, 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	Atmosfilter	Inside filtering, upward flow; Ultrafiltration equipment 1800-16200 ft^2	
Ducon Company, Inc. 157 East Second Street Mineola, Long Island,NY 11500	UFV Bin Vent	Inside filtering, upward flow bags; 20-200 ft^2; intermittent	Shake, manual or motor
	UFS Unit	Inside filtering, upward flow bags; 40-200 ft^2; intermittent	Shake, Manual or motor
	Uniflow	Inside filtering, downward flow tubes 880 ft^2 and 1320 ft^2 modules Continuous	Reverse flow alternating with primary flow; adjustable timer.
	FD	Inside filtering, upward flow, large bags 50-400 ft^2; intermittent. For larger particles.	Manual inversion
Dustex Division American Precision Industries 2777 Walden Avenue Buffalo, New York 14225	Inductaire	Inside filtering, upward flow bags; 800 ft^2 and up Modular; continuous. Custom designs	Forward pulse at top; plus induced vacuum.
	RA	Ouside filtering, upward flow bags; 225-8500 ft^2 Continuous, designed for felts.	Quick reverse flow Automatic via timer.
Dusty Dustless 2914 E. Genesee Street P. O. Box 86 Baldwinsville, N.Y. 13027		Inside filtering upward flow bags; Intermittent	Shake, powered
	Silo Vents	85-250 ft^2	Timer.
	Batcher Vents	12, 18 ft^2	Manual.
	Clean-A-Batch	400 -1500 ft^2	Timer
	Dust Houses	500 -6000 ft^2	Timer

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
Environmental Research Corp. 3725 N. Dunlap Street St. Paul, Minn. 55112	Series H	Inside filtering, upward flow bags	
	-HI	392 - 3136 ft^2	Shaker, non-automatic or timed.
	-HA	625 ft^2 and up Intermittent or continuous; Modular	Shaker, reverse flow, or both; automatic
	-HC	125 - 1300 ft^2 Intermittent, top inlet, open or closed cylindrical housing.	Automatic option
Flex-Kleen Division (Research Cottrell, Inc) 407 S. Dearborn Street Chicago, Illinois 60605		Outside filtering, upward flow bags;	Reverse pulse, Adjustable timer.
	Flex-Kleen	Continuous; felt	
	-FK Series	58 - 1200 ft^2, cyclone inlet	
	-CT Series	15 - 2000 ft^2, also cylindrical	
	-UD Series	Up to 10,000 ft^2 est; modular	
	-RA Series	320 - 960 ft^2, modular	
	-BV Series	17 - 250 ft^2 (binvent type)	
Fluidizer, Inc. Hopkins, Minn.	Ultrajet	Outside filtering, upward flow bags; Continuous	Vortex induction of reverse flow air with pulse
Hoffman Air & Filtration Div. Clarkson Industries Inc. P. O. Box 214 Eastwood Station Syracuse, New York 13206	Dustuctor	Inside filtering, upward flow bags; Intermittent	Shake
	HoffcoVac	Inside filtering, upward flow bags; 30, 63 ft^2, intermittent Portable	Shake, Manual or Powered
Hydromation Engineering Co 39201 Amrhein Road Livonia, Michigan 48105		Top inlet housing; tubes 100 - 1000 ft^2 Continuous	Reverse pulse; Timer
Johnson-March Corporation 3018 Market Street Philadelphia, Pa. 19104	Series MB	Inside filtering, upward flow bags; 250 - 1250 ft^2 Continuous or intermittent	Reverse flow or shake; timer.

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	Series 1000	Inside filtering, upward flow bags; 1,750 - 21,000 ft^2 Modular, continuous access	Reverse flow via adjustable timer (shaker option).
Kice Metal Products Company 2040 South Mead Avenue Wichita, Kansas 67211	DynaJet	Outside filtering, upward flow bags; Continuous	Reverse pulse, adjustable Pneumatic timer and controls
	- Series C	10-86 ft^2; compact	
	- Series S	75-930 ft^2; floor type, square housing	
	- Series R	75-891 ft^2; round housing cyclone inlet option.	
	- Series M	170 ft^2 and up; 170 or 233 ft^2 modules	
Kindt Collins Company 12651 Elmwood Avenue Cleveland, Ohio 44111	Master Model 550	Single bag cleaner 20 ft^2 est.	Collapse, manual shake
	Ventomatic	Air control damper	
Lamson Division Diebold, Inc. 306 Lamson Street Syracuse, New York 13201	Exidust	Inside filtering, upward flow bags; 38 - 727 ft^2	Shake, manual or automatic
Macleod Company 125 Mosteller Road P. O. Box 452 Cincinnati, Ohio 45421	Type SV	Envelope; 880 - 13,300 ft^2; intermittent Also continuous, via automatic damper control	Shake, manual or motored.
	Unit Type	Envelope; 180 - 1500 ft^2; intermittent	Shake, manual or motored
	Tube Type	Inside filtering, upward flow bags; 800 - 6560 ft^2	Shake

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
R. C. Mahon Company 6565 East Eight Mile Road Warren, Michigan 48234		Envelope type, upward flow; 265 ft^2 and up	Reverse pulse
		Conventional sectional type	Shake
Wm. W. Meyer and Sons, Inc. 8262 Elmwood Avenue Skokie, Illinois 60076		Felt Tubes 85-930 ft^2, continuous Mobile dust collectors Rotary air lock feeders	Reverse pulse
Pangborn Corporation P. O. Box 380 Hagerstown, Maryland 21740	Type CH-3	Envelope; 400 ft^2 and up	Reverse flow, from continuous traversing blower
	Type CM	Inside filtering, upward flow bags; 1360 ft^2 and up; modular Intermittent, 6 tubes per element	Shake, periodic
	Type CH-2	Envelope; 4080 ft^2 and up Intermittent or continuous	Motor-driven rapping of screens
	Type CO	Inside filtering, upward flow bags; Modular 1000 est ft^2 and up Continuous	Reverse flow alternating with reverse pulse; adjustable timer
	Unit Type CN	Similar to Type CM. 200 to 1500 ft^2	Shake, periodic
	Unit Type CD	Envelope; 180 to 720 ft^2. Intermittent	Hand vibration
	Type CT	Inside filtering, upward flow bags; 1770 - 6726 ft^2, intermittent, manometer	shake adjustable
	Poisi-pulse	Outside filtering, upward flow bags; pneumatic control	Reverse flow and pulse; automatic

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	- compact	11 - 85 ft^2	Shake, once in 2 to 3 years.
	- square	77 - 930 ft^2	
	- round	77 - 892 ft^2, cyclone inlet option	
	- modular	510 - 3350 ft^2; 510 or 670 ft^2 modules	
	Totalaire	Untrafiltration via filter aid; std. units or custom design	
		Fume control hoods, ducts.	
		Fiber, fabric R&D, all types of cloths	
Perlite Corporation 200 E. Duttonmill Road Chester, Pa. 19014	Type "H"	Inside filtering, downward flow, tubes continuous compartmented	Reverse flow, electric timer for separate draft fan on each compartment.
Precipitair Pollution Control, Inc Chimney Rock Road Bound Brook, N. J. 08805		Inside filtering; downward flow, tubes with sewn-in rings	Reverse flow
Pulverizing Machinery Div. The Slick Corporation 10 Chatham Road Summit, N. J. 07901	Mikro-pulsaire	Outside filtering, upward flow bags; Continuous	Reverse pulse, timer.
	- Modular	340 ft^2 and up, in 100 to 200 ft^2 modules	
	- Binvent	25 - 84 ft^2	
	- Cylindrical	42 - 900 ft^2	
	- "S"	112 - 930 ft^2	
	Mikro-collector	Inside filtering; downward flow tubes; 25 ft^2 and up; continuous	Reverse jet.
	Mikro-Custom	Inside filtering; upward flow bags; 3300 ft^2 and up; compartmented	Reverse jet via pulsed outlet plenum

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
Rees Blow Pipe Manufact. Co. 2929 Fifth Street Berkeley, California 94710	Standard	Inside filtering, upward flow bags; 1400 - 22,400 ft^2 Intermittent	Shake, electric
	AE Series	Inside filtering, upward flow bags; 700 - 22,400 ft^2	Shake, electric, automatic
	ANS Series	Inside filtering, upward flow bags; 1500 - 24,000 ft^2 Continuous	Reverse flow, automatic
	Unit Collectors	Inside filtering, upward flow bags; 380 - 860 ft^2 Intermittent, integral fans.	Manual, electric shake
		Also: Conveyors, valves, blowers	
Research Cottrell, Inc. P. O. Box 750 Bound Brook, N. J. 08805		Inside filtering, upward flow bags;	
	Air Shake	3927 - 15,700 ft^2 std, and up continuous, intermittent	Shake by air between rows of bags; automatic
	Shake-Kleen	1600 - 12,800 ft^2 std. Intermittent, modular	Shake, mechanical
	"	4,800 - 19,200 ft^2 std continuous, modular	Semi or full automatic via adjustable timer
	Uni-Kleen	295 - 1860 ft^2 Intermittent	Shake, mechanical Adjustable timer.
	Flex-Kleen	- See Flex-Kleen Corporation	
		Also valves, damper, conveyors, shaker drives, timers.	

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
Ruemelin Manufact. Co. 3860 North Palmer Street Milwaukee, Wisconsin 53212	Tubular Types	Inside filtering, upward flow bags;	
	- Unit, Portable	53 - 755 ft^2 Intermittent	Shake, manual or electric
	- Standard	1000 - 9155 ft^2 - Intermittent - one compartment - Continuous - two or more compartments	Shake, powered, timer.
Systems Engineering and Manufacturing Co. (SEMCO) 6330 Washington Avenue P. O. Box 7634 Houston, Texas 77007		Outside filtering, upward flow, supported bags;	
	Semco	Continuous; removable manifold header for quick bag change	Reverse pulse, 5-15 psig, adjustable timer
	DC-Large	1250 - 3112 ft^2	
	DC-Remote	72 - 780 ft^2, cylindrical	
	DC-Mini	8 - 30 ft^2 cylindrical	
	DCV	72 - 780 ft^2 (binvent), cylindrical	
Setco Industries, Inc. 5880 Hillside Avenue Cincinnati, Ohio 45233		Envelope, suspended	
	Types 7 AR, 7 GAR & AB1	50 ft^2 est.	Manual (also disposable)
Seversky Electronatom Corp. 30 Rockefeller Plaza New York, New York 10020		Inside filtering, upward flow, bags;	
		200 ft^2 and up Modular	Reverse flow, collapse or shake
W. W. Sly Manufact. Co. P. O. Box 5939 Cleveland, Ohio 44101		Envelope types, supported	
	Pactecon	88 - 1065 ft^2; modular	
	- PC Series	Continuous	Reverse pulse series; timer
	- PS Series	Intermittent	Shake, manual
	Dynaclone	Continuous	Reverse flow from traveling carriage.
	- A Type	2244 ft^2 and up, 3 tiers	
	- B Type	1496 ft^2 and up, 2 tiers	
	- C Type	748 ft^2 and up, 1 tier	

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
	Intermittent	Intermittent	Shake and reverse flow Auto - or semiautomatic
	- 360 type	1122 ft^2 and up, 3 tiers, modular	
	- 260 type	748 ft^2 and up, 2 tiers, modular	
	- Unit	242 ft^2 and up, 1 tier	
	Economy	176 - 352 ft^2; intermittent	Shake, manual
		Also hoppers and support stands.	
Smico, Inc. 500 N. MacArthur Blvd. Oklahoma City, Okla.	Suction	Reverse pulse cleaned model	
Sprout-Waldron & Co. Inc. Muncy, Pennsylvania 17756		Inside filtering, upward flow bags;	
	Multi-tube	74 or 100 ft^2, intermittent Removable tube frame for quick change of tubes.	Shake, manual or powered
	Series type	46 - 453 ft^2; intermittent	Flex
	BV	12 - 27 ft^2 single bag	Flex
Sterling Blower Company 771 Windsor Street Hartford, Connecticut		Inside filtering, upward flow bags;	
	Type "R"	111 - 552 ft^2 Intermittent	Rap at tube bottom
Sternvent Company, Inc. 12 Van Dyke Street Brooklyn, New York, 11231	Cabinet Type	Envelope, suspended. Intermittent	Shake, manual or powered
	- 200 Series	32 - 120 ft^2	
	- 1000 Series	700 - 1200 ft^2	Automatic option
		Inside filtering, upward flow, bags;	
	Filtertube	426 - 1800 ft^2; Intermittent. manometer	Shake, powered
		Also inside filtering downward flow tube-cyclone combination.	
Tailor and Company, Inc. 2403 State Street Bettendorf, Iowa 52722		Inside filtering, upward flow, bags;	
	Controlled Cycle	400 ft^2 est and up; modular	Reverse pulse with adjustable shake option.

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
		Continuous. Controlled tube tension Rotary lock feeders for high pressure transfer.	Adjustable timer, controlled re-start
Torit Corporation 1133 Rankin Street St. Paul, Minnesota 55116	Unit types, 10 Models	Envelope, suspended. 30 - 1200 ft^2 Intermittent Also hoods and flexible ducting	Shake, manual or powered
United McGill Corporation Dust Collector Division 883 North Cassady Avenue Columbus, Ohio 43219	RF	Envelope, continuous	Reverse flow, pressure control
	VAV	Envelope	Adjustable vibration
	MHS	Inside filtering, upward flow bags; compact	Shake
	High Temp	Inside filtering, upward flow, bags	Reverse flow
UOP Air Correction Div. P. O. Box 1107 Darien, Connecticut 06820	Aeropulse	Outside filtering bags; 4200 - 22,000 ft^2, modular Continuous access. Systems including fans, etc. also available. Organic fabrics.	Reverse pulse; fan with chopper; adjustable timer.
Joy Manufacturing Company Western Precipitation Div. P. O. Box 2744 Terminal Annex Los Angeles, California	Pulse Flo	Outside filtering, upward flow, bags Continuous access from outside	
	-C8	75 - 1135 ft^2, (cylindrical)	Reverse pulse in sealed bag. Adjustable timer.
	-M8	1130 - 11,300 ft^2; modular, continuous access	
	Therm-o-flex	Inside filtering, upward flow, bags; compartmented	Reverse flow collapse or shake.

FABRIC FILTER MANUFACTURERS SUMMARY 1969 (Cont.)

Manufacturer	Trade Name	Characteristics	Method of Cleaning
Wheelabrator Corporation Air Pollution Control Div. 400 South Brykit Street Mishawaka, Ind. 46544	Dustube	Inside filtering, upward flow, bags	Shake, powered
	- Model 112-D and 126-D	893 ft^2 and up; intermittent or continuous, manometer	Automatic
	- Model 70-AC and 70-BC	273 - 730 ft^2	
	- Continuous automatic type, 10,000 ft^2 est. range.		Timed shaker.
		Outside filtering, upward flow, bags	
	Ultra-Jet	Continuous	Reverse pulse.
	Ultra-Filtration	Same equipment but with pre-treated cloth plus filter aid.	
		Also hood and duct designs.	
Young Machinery Company Painter St. and Schuyler Ave. Muncy, Pennsylvania 17756		Outside filtering, bags	
	Uni-cage	Continuous	Reverse pulse; adjustable solid-state timer.
	- VC	39 - 1523 ft^2; cylindrical, upward flow	
	- Modular	780 ft^2 and up; modular, upward flow	
	- Horizontal	27 - 368 ft^2, Horizontal tubes	
		Inside filtering, upward flow, bags	
	Shaker-type	94 - 631 ft^2 Intermittent	Shake, powered
		Air locks, solenoid values, timers.	

APPENDIX 3.2

EXAMPLE OF EQUIPMENT MANUFACTURER'S SPECIFICATIONS

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Shake-Kleen Fabric Filter Dust Collector*

Unless otherwise noted, items described in the attached proposal shall meet with the specifications as listed below:

FABRICATION

Housing - All panels to be fabricated of #14 gauge mild steel sheets conforming to the latest ASTM specifications. All sheets to be flanged and punched for bolted assembly. Adequate structural stiffeners to be shop applied to meet design requirements. Appropriate panels to have cutout and framing to accept 18" x 36" access door.

Hopper - To be fabricated of #14 gauge mild steel sheets conforming to the latest ASTM specifications. Sheets to be shop assembled using welded construction; flanged and punched for field bolting to the housing. All pressure holding welds to be gas tight and to be applied in such a manner as to minimize distortion of the metal. Hoppers include hinged access hatch and flanged discharge opening. Adequate stiffeners to be shop applied to meet design requirements.

Floor - To be fabricated of #10 gauge mild steel sheets conforming to the latest ASTM specifications. All sheets to be flanged and punched for bolted assembly. Each floor section includes one access walkway 1'-6" wide. Adequate 5" diameter holes are machine punched into floor panels to accept filter bags. Shop applied stiffeners to be attached to meet design requirements.

Structural Supports - All necessary columns, beams, secondary bracing and base plates to be designed and fabricated in accordance to ASTM A-36 latest edition. All connections shall be capable of resisting the moments, shears, and axial loads to which they would be subjected by the maximum load.

Catwalks and Platforms - Expanded metal catwalks 2'-6" wide designed in accordance with ASTM standards to withstand maximum allowable loads. All catwalks to include rod type handrail with midrail and kick plate.

Ladder & Cage - Bar type stringer with 3/4" diameter rungs spaced at 1'-0" centers. No more than 15'-0" of ladder shall be installed without the addition of a safety cage, approximately 2'-0" in diameter, constructed of bar stock hoops and rails.

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*Courtesy of Research Cottrell, Inc.

Ducts & Piping - Fabricated of welded 14 gauge mild steel construction. Ducts may be round or rectangular depending on the design requirements, but both types will be adequately stiffened to safely accept the design requirements. All connecting flanges to be in accordance with Research-Cottrell standards.

Bolts - All necessary structural bolts shall be of proper size and quality as to meet the latest ASTM specifications.

Shop Paint - All fabricated steel surfaces to be properly cleaned and given one shop coat of machinery gray enamel.

Welding - Welding electrodes shall conform to section 3 of the "Standard Code for Arc and Gas Welding in Building Construction". Section 4 of this code shall be followed for the technique of welding employed, the appearance and quality of welds made, and the method used in correcting defective welds.

Shaker Mechanism

The Research-Cottrell shaker mechanism is designed to deliver a combination of horizontal and slight vertical motion at the top of the filter bags, resulting in a rolling wave action transferred throughout the bag. The motion is created by a mechanism assembled on a mounting plate and bolted to the side walls of the collector casing. The drive mechanism consists of the following items:

A. Totally enclosed, fan cooled ball bearing, polyphase squirrel cage induction motor, 1800 RPM, 230/460 volts - 60 cycle - 3 phase current.

B. Single or double groove cast iron sheaves (depending on the collector size) coupled by V-belts to drive shaker mechanism at 400 R.P.M.

C. Eccentric cam shaft, secured in place by two ball bearing pillow blocks, rotated by the driven sheave.

D. Hanger type bearing mounted on the eccentric portion of the cam shaft to translate rotary motion of cam shaft to lateral motion for shaker.

E. 3/4" diameter connecting rod, threaded at both ends, joins eccentric bearing to a rod end bearing with teflon seat. Rod end bearing connects to the filter bag hanger assembly.

Filter Bag Hanger Assembly

Filter bags are suspended on individual 'J' hooks welded to rocker frames. Each rocker frame supports two rows of bags and is made up of two structural angles spanning the 8 ft. width of the collector, supported by two pillow blocks with self-aligning, self-lubricating, graphite bearings. At the center of each rocker frame, below the frame center line is attached a rigid connecting shaft which connects all the rocker frames to the shaker mechanism connecting rod. All the connections between the connecting shaft and the rocker frames are made with pillow blocks with self-aligning, self-lubricating, graphite bearings. A 3/4"diameter shoulder bolt fastens the connecting shafts to the pillow block bearings.

Filter Bags

Each filter bag is specifically designed and manufactured for your dust type to insure maximum filtering efficiency, together with long range life expectancy. Within the bottom cuff of each bag is sewn cadmium plated steel coil spring rings. These rings are installed in such a manner that by compressing the bottom ring and inserting it through the floor of the collector and releasing, it will expand (leaving the floor plate between the rings), thus causing a dust tight seal between the hopper and the collector housing.

At the top of each bag is sewn a 12" strap and positive grip buckle. For the installation, the strap is looped over the 'J' hook, on the hanger assembly, and back through the buckle. By pulling on the remaining end of the strap, the desirable bag tension may be easily secured.

APPENDIX 4.1

GLOSSARY OF FABRIC TERMINOLOGY

GLOSSARY OF FABRIC TERMINOLOGY*

Absorption. The property to attract and hold gases or liquids within the pores of a fiber, yarn or fabric. (See also adsorption).

Adsorption. The attraction of gases, liquids, or solids to surface areas of textile fibers, yarns or fabrics.

Backing. The yarn system which produces the lower or back structure in a fabric.

Basket Weave. A plain weave with two or more warp and filling threads interlaced to resemble a plaited basket. Produces a flat appearance, porosity, and looseness or "give" in a fabric. Can be heavy or light weight and made of any fiber.

Body. The compact, solid or firm feel of a fabric.

Bolt. The entire length of cloth from the loom, rolled or folded, of varying length.

Bulking Processes. These are recent developments in treating man-made yarns, principally filament. Building processes fluff up yarns, giving soft, pleasant textures and opaque effects to both knitted and woven fabrics.

Cabled Yarn (U.S.A. Cord). Yarn produced by twisting together two or more plied yarns.

Calendering. A process for finishing cloth by applying heat and pressure from rollers.

Canvas. Cotton, linen, or man-made yarn fabricated in an even, heavy, firm weave for sails and industrial purposes.

Carding. An operation which opens and cleans fibers, separates the individual fibers, and delivers them in sliver form or as a carded web.

Cellulose. A carbohydrate of complex molecular structure which forms the chief framework of plant cells and walls. Used as a principal basic raw material for all existing commercially successful processes for making rayon and acetate.

Cloth, Backed. A term referring to cloth which, in addition to the face fabric, holds underneath a layer, either of extra filling or extra warp, adding weight.

Combination. A term which may refer to yarns or to fabrics: (1) A combination yarn may be composed of two or more yarns having the same or different fibers or twists: one yarn may have a high twist, the other little or no twist; one may be viscose, the other acetate yarn. (2) A combination fabric is one which employs the above yarns, e.g., mossy crepes, romaines, alpacas, etc.

Combing. The process of straigntening of fibers and extraction of short, broken fibers, neps and foreign matter.

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*From J. J. Press, Man-made Textile Enclyclopedia, Textile Book Publishers, Inc., Div. Interscience Press Inc., New York (1959)

Compliance. In fibers, elongation produced by any load. Inverse of stiffness, considered to affect the feel of fabrics as they are squeezed in the hand. Ability to yield under stress; the ratio of change in strain to the change in stress which produces it; the reciprocal of the textile modulus.

Conditioning: The process of putting materials into the condition of proper moisture content.

Cord. The product formed by twisting together two or more ply yarns.

Count. (1) Cloth: number of warp and filling yarns per inch in woven cloth. (2) Yarn: size or weight per unit length of yarn. (3) Number of wales and courses per inch in a knit fabric. (4) Count of Reed: The number of spaces per unit width of reed. (5) Term designating the number of wires per unit area of card clothing.

Cover Factor. Fraction of the surface area which is covered by yarns assuming round yarn shape. The value indicates the compactness of the weaving of a given yarn system (warp or fill).

Creep. The gradual deformation resulting from application of a load or stress to a material. Creep is subdivided into the two following types: primary creep, which is recoverable after a more or less extended time and secondary creep, which is not recoverable and represents true plastic flow.

Creep Recovery: The gradual recovery of form of a material after removal of stress.

Crimp. Fiber: The waviness in fibers, e.g., certain wools and man-made staple fibers. (2) Yarn: Also curvature produced in warp or filling yarn by weaving.

Deformation, Permanent. The residual change in shape of a specimen after removal of an applied stress. Sometimes this includes removal of internal strains, e.g., relaxing strains which have been created by drying under tension, by wetting, and redrying without tension.

Denier. Name of an old French coin formerly used in weighing silk yarns to determine fineness. The term denier is now also used as the unit of weight expressing the size of most man-made yarns and fibers. The weight, in grams, of yarn or fiber is the denier. The lower the denier, the finer the yarn. For example, 50 denier rayon is twice as fine as 100 denier rayon.

Density, Linear. Mass per unit length expressed as grams per centimeter, pounds per foot, or equivalent. See also yarn number.

Double Weave. A cloth woven with two systems of warp or filling threads so combined that only one is visible on either side.

Doubling. (1) The operation of combining several strands to form a single strand without twisting. (2) Plying or twisting.

Duck. A comparatively firm, heavy, plain weave, cotton or man-made yarn fabric, weight per square yard 6-50 oz. There are two general types of duck based on construction: (1) Regular duck, in which both the warp and filling yarns are plied and unsized, such as numbered, army, hose, and belting duck. (2) Flat duck, in which the warp yarns are single, sized, with two strands of yarn woven as one warp end, interlacing as a unit with one filling yarn which is either single or plied.

Elasticity. That property of a material by which it recovers its original size and shape immediately after removal of the stress causing deformation.

Elongation. The deformation in the direction of load caused by a tensile force. Elongation is expressed as a percentage of the original length and it may be measured at any specified load or at break.

Extension. The longitudinal strain in a tensile test, that is, the elongation expressed as a fraction of the initial length.

Fabric. A collective term applied to cloth no matter how constructed or manufactured and regardless of the kind of fiber from which made. In structure it is planar produced by interlacing yarns, fibers, or filaments. Textile fabrics include the following varieties: bonded, braided, felted, knitted, and woven.

Fabric, Laid. A fabric made without filling yarn whose parallel warp yarns are held together with a bonding material.

Fiber. (1) General: The fundamental unit in the fabrication of textile yarns and fabrics. (2) Specific: A unit of matter characterized by having a length at least 100 times its diameter or width, and, with the exception of noncrystalline glass fiber, having a definitely preferred orientation of its crystal unit cells with respect to a specific axis. (3) Textile: Fibers that can be spun into a yarn and made into a fabric by interlacing in a variety of methods, including weaving, knitting, felting, braiding, and twisting. The essential requisites for fibers to be spun into yarn include a length of at least 5 mm., pliability, cohesiveness, and sufficient strength. Other properties, more or less desirable, include elasticity, fineness, uniformity, durability and luster.

Filament. A variety of fiber having an extreme length, not readily measured. Note: the extreme length of filaments permits their use as yarns with little or no additional twist and without the spinning operations required to convert fibers to yarns.

Filling. (1) Yarn running from selvage to selvage at right angles to the warp in a woven fabric. (2) Yarn to be used as filling in weaving. Note: Filling yarn is also designated as "weft" and occasionally as "woof."

Finishing. General term for variety of processes by which woven fabrics are converted into finished goods. Bleaching, mercerizing, application of resins, printing, calendering, singeing, shearing, and dyeing are some of the finishing processes.

Flannel. A fabric with a characteristic soft or napped surface cover, plain or twill weave. May contain woolen, worsted, cotton, or man-made fibers.

Flexibility. (1) That property of a material permitting it to be flexed or bowed repeatedly without undergoing rupture. (2) A term relating to hand of fabrics, and referring to ease of bending, ranges from pliable (high) to stiff (low).

Friction, Surface. A term relating to the hand of fabrics, and referring to resistance to slipping offered by the surface. Ranges from harsh (high) to slippery (low).

Fulling. The process in the finishing of woolen cloth of interlocking wool fibers to a dense, felty condition by means of friction, heat, and moisture. Also termed milling. In limited quantities man-made staple may be blended with wool without adversely affecting this operation.

Gray Goods (Also Grey or Greige Goods) Woven or knitted fabrics which have received no bleaching, dyeing, or finishing treatment.

Grex. A yarn number defined as weight in grams of 10,000 m of yarn.

Hand. Term used to described the touch or "handle" of fabrics.

Harness. The frame holding heddles in a position in the loom during weaving. Also known as shaft.

Heat Setting. Most thermoplastic fibers can be set to any form by heat treatment and will then be dimensionally stable until again heated to or above the setting temperature.

Knitting. The art of producing fabric on more than one needle by method of interlooping one or more yarns.

Length, Breaking. The calculated length of a yarn which has just sufficient mass to break of its own weight. This term is used widely on the continent and is expressed in kilometers.

Load, Breaking. The maximum load developed in a test specimen during a strength test carried to rupture.

Loom. A weaving machine for producing a fabric by interlacing warp and filling yarns.

Mat, Bonded. A sheet or random web of fibers held together by a bonding agent.

Mechanical Fabrics. A large class of heavy fabrics used in various industries. E.g., sheeting for the laundry supply trade, drill for oil and chemical filters, and duck for the tent and awning trade.

Modulus of Elasticity. The load required to stretch a specimen of unit cross-sectional area a unit amount. Expressed in dynes per square centimeter, kilograms per square millimeter, or pounds per square inch.

Modulus. The ratio of change in stress to change in strain in the initial straight line portion of a stress-strain curve following the removal of any crimp. The ratio is calculated from the stress expressed either in force per unit linear density or force per unit area of the original specimen, and the strain expressed either as a fraction of the original length or the strain expressed as percentage elongation.

Monofil, Monofilament. Any single filament of sufficient size to function as a yarn in normal textile operations. Monofils as low as 8 den. are in common use.

Multifilament. A trade term loosely used to described filament yarns having more than the normal number of individual filaments for a particular fabric or in a given style season. Multifilament yarns produce exceptionally soft fabrics.

Nap. The hairy surface of a cloth produced by raising, gigging, or napping.

Pile Fabric. Fabric with cut or uncut loops which stand up on the surface. Not to be confused with napped fabrics that have brushed surfaces. E.g., velvets, plushes, corduroys, and most woven and tufted floor coverings.

Plain Weave. The simplest of the fundamental weaves producing a fabric pattern in which each warp yarn passes alternately over and under one filling yarn.

Ply. (1) The number of single yarns twisted together to form a ply yarn. Also the number of ply yarns twisted together to form a cord. (2) The individual yarn in a ply yarn or cord. (3) One of several layers of fabrics.

Satin. A fabric with a lustrous surface. Fabric with satin weave. Originally silk, now made extensively in rayon and other man-made filament yarns in many qualities.

Scrim. A coarse, open fabric of plain weave. Used for curtains and backing material in high strength papers, for needlework. Also made in bonded nonwoven fabric.

Setting. Stabilizing (1) the dimensions of cloth or (2) the twist in yarn.

Shrinking. Treating any type of fabric so as to remove most of the tendency to shrink.

Slippage. The sliding or slipping of the warp threads along the filling threads (or vice versa) in a woven fabric of very smooth yarns or loose weave. Sometimes useful in fabrics where extended bias stretch is wanted.

Spinning. (1) General: The process of making yarns or cordage from fibers, tow, or liquid materials. (2) Yarn from fiber: The formation of a yarn by a combination of drawing or drafting and twisting operations applied to prepared fiber masses such as rovings. (3) Filament yarn: The extrusion by pressure through a spinneret of a liquid or solution into a coagulating medium which produces a solid filament or filaments. (4) Yarn from filament tow: The formation of a yarn from filaments by the combination of cutting or breaking together with drafting and twisting in a single series of operations.

Staple. (1) A term denoting the average length of any species of fibers. (2) In the case of man-made fibers, spinnable lengths cut from filaments. Does not include fibers from cut waste. (3) Sometimes used as an index of quality or fineness as "long staple." (4) Any fabric or article sold year after year in contrast to a novelty.

Stitch. In knitting, the manner of interlooping of the yarns. Common stitches are the plain, tuck, welt, and float stitch.

Strength, Breaking. The ability of a material to resist rupture by tension.

Stress. Force per unit area of cross section, e.g., lb. per square inch, kilograms per square millimeter. The area is generally that of the unstrained specimen and, unless otherwise stated, it is the area of cross section of the solid fiber material.

Tenacity. (1) A measure of yarn strength. (2) Tensile stress expressed in terms of force per unit linear desnity as grams per denier, or grams per tex.

Thread: (1) Strand of yarn. (2) Sewing: A variety of yarn, normally plied, characterized by a combination of twisting and finishing with solid or semisolid, wax-like materials to secure a smooth compact strand which is quite flexible but presents no loose fibers. (3) The ply of yarns, sometimes referred to as the number of threads, as two thread for two ply.

Tow. (1) In man-made fibers, a heavy multifilament strand suitable for cutting into staple or flock, or for conversion into spun yarn. (2) In bast fibers, the short fibers removed by hackling.

Twill. A weave characterized by diagonal lines or ribs produced by staggered floats. Warp face twills have prevalently warp floats on the face, filling face twill has filling floats. One of the basic weaves; permits heavier denser cloth than plain weave.

Twist. The turns about their axes of fibers, yarns, or cords. Expressed in turns per unit of length or, less commonly, by the helix angle in reference to the diameter of the yarn.

Warp. (1) The yarn running lengthwise in a woven fabric. (2) A group of yarns in long lengths and approximately parallel, put on beams or warp reels for further textile processing including weaving, knitting, twisting, dyeing, etc.

Weave. (1) A particular method or pattern of weaving, such as plain weave, twill weave, leno weave, etc. (2) A woven fabric. (3) To form, as a textile, by interlacing yarns or similar strands of material; specifically, to make a fabric on a loom by interlacing warp and filling yarns.

Woof. See filling.

Yarn. A generic term for continuous strands of textile fibers or filaments in a form suitable for knitting, weaving, or otherwise intertwining to form a textile product. It may comprise (a) a number of fibers twisted together, (b) a number of filaments laid together with twist (a zero-twist yarn) (c) a number of filaments laid together with more or less twist, or (d) a single filament without twist, a monofilament. Note: Varieties include single yarn, plied yarn, cord, twine, sewing thread, etc.

Yarn Number. A measure of linear density. Two systems are in current use: (1) Direct yarn numbers (equal to specific linear density):

$$\text{Yarn Number} = \frac{\text{Observed linear density}}{\text{Linear density of a No. 1 Yarn}}$$

Direct yarn numbers are based on weight per unit length; (2) Indurect yarn numbers (equal to the reciprocal of the specific linear density).

Yarn, single. An aggregate of twisted fibers or filaments. Two or more single yarns twisted together form a ply yarn.

APPENDIX 4.2

SOME INORGANIC AND METAL FIBERS POTENTIALLY SUITABLE FOR HIGH TEMPERATURE FILTRATION OR CONTROL OF ELECTROSTATIC EFFECTS IN FABRICS

INORGANIC FIBERS*

trademark	description	source
AVCERAM	USA continuous filament ceramic fired fibers for reinforcing ablative materials 2 25 microns dia rocket and space research to resist high temp. unfired yarns may be knit or woven **-CS**: Carbon silica fil yarn higher strength than RS **-RS**: Rayon silica ablative composite reinforcement	**FMC**
FIBERFRAX	USA alumina silica fiber in bulk, yarn, woven, non woven forms, with good electrical insulation characteristics, capable of continuous operation up to 2300°F	**Carborundum**
HMG-25	USA high modulus filament graphite yarn, average elastic modulus 25 million lbs sq in tensile strength 150.000 psi, aircraft structural reinforcements, missile components	**Unknown**
HYFIL	British carbon fibers developed in cooperation with Royal Aircraft Establishment, stiff, strong, light weight, manufactured in three stage process. acrylic fiber is oxidized at 200 300°C. carbonized at 1000°C. converted into carbon (graphite) fibers at 3000°C. Shirley Institute developed spinning technique, designed and built prototype weaving unit, fabric made from fibers is an integral part of RB 211 aero engine, allows for better power to weight ratio (for own use only)	**Rolls-Royce**
LEXAN	USA acrylic-latex polycarbonate fiber in early development, space-age textiles	**General Electric**
QUARTZ FIBERS	USA yarn, mat, roving overlay, wool, structural fil winding, wire sewing, radomes, insulation, impregnating, ablative applications	**General Electric**
REFRASIL	USA patented leaching process for making high quality silica-fiber material, licensed basis	**Hitco**
ROCKSIL	British dolomite rock-based staple, non-textile uses	**Cape Insulation**
THORNEL	USA continuous graphite filament yarn, converted from rayon yarn (patents pending) **-25**: Filamentary modulus of elasticity 25 million psi, tensile strength 200.000 psi, woven into fabric by Fabric Research Laboratories, Inc **-40**: Modulus 40 million psi, density 0.056 lb/cu in, tensile strength 250.000 psi, aircraft, aerospace structures **-50**: Modulus 50 million psi, tensile strength 285.000 psi, reinforcing agent for composite structures	**Union Carbide**

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* From A.A. Dembeck, Guidebook to Man-made Textile Fibers and Textured Yarns of the World, 3rd Edn., The United Piece Dye Works, New York (1969).

Inorganic Fibers (continued)

trademark	description	source
VILIWYTE	USA rayon filament yarn for conversion into carbonized or graphitized fabrics, yarns, chopped fibers; carbonized or graphitized product is used in ablative materials, resist high temp., missile parts, corrosive chemical handling, insulation	**Midland-Ross**
WHISKERS	Generic term for single crystal fibers	
UNNAMED	USA boron filaments	**Avco**
	USA 99.5% pure carbon yarn, neutral pH, as flexible as wool yarn, can be woven, knit, braided, wound, variable electrical resistivity, corrosive resistant	**Basic Carbon**
	USA boron nitride staple, similar to graphite in crystal structure, with advantage of lubricity and mechanical properties, density 1.8-2.0, good elastic modulus, whiteness, withstands temperatures in inert atmosphere to 5000°F., in air or oxygen to 1800°F., chemically inert, abrasive resistant, dielectrically strong; uses: high-temperature composite reinforcement of steel and other metals, aerospace thermal shields, space suits, and dust collector bags ($175 per lb.)	**Carborundum New Products Branch**
	USA carbon and graphite 600 dr. filament yarn, 720 filaments per ply, chopped fibers, tapes, and fabrics, 100% pure elemental carbon, strong, flexible, thermal stability to 5700°F., unaffected by thermal shock, suited for uses in automatic winding equip., weaving, knitting machines, aerospace ablatives, resistance heating, electrolysis, filtration	**Carborundum Graphite Products Div.**
	USA silicon carbide coated carbon/graphite fiber, increased oxidation resistance at high temperatures, better mechanical bond in resin composites, ablative heat shields, rocket nozzles ($250-$500 per lb.)	**Carborundum Graphite Products Div.**
	USA silicon carbide single crystal fibers called "whiskers", high-tensile strength, resist temperatures to 2200°F.; reinforcing agent for light weight metals, ceramics, plastics ($250 per lb.)	**Carborundum New Products Branch**
	British high-strength graphite fiber produced from polyacrylonitrile, aircraft and aerospace structures requiring high strength and stiffness with minimum weight, shear properties	**Courtaulds**
	Exclusive sales licensee with option to manufacture in USA	**Hercules**
	USA boron filaments	**General Elec. Chemical-Metallurgical Div.**
	USA boron filaments	**General Technologies**
	USA boron filaments in early development	**Monsanto**
	USA and British graphite fiber made from acrylic fibers	**Morganite**
	British pioneering work on new types of carbon fibers which when mixed with resin or plastic are said to be stronger than steel, see also HYFIL, page 129	**Royal Aircraft**
	USA high-purity graphite filaments and fibers in development NASA R/D contract, missiles, space ships and stations	**Space Age**
	USA sapphire whiskers, $3,500 per lb	**Thermo-kinetic**
	USA boron filaments	**United Aircraft**

METAL FIBERS

trademark	*description*	*source*
BRUNSMET	USA stainless steel filament yarn staple sliver short fibers web 8 12 25 micron Types 304 310 316 347 also nickel base super-alloy, for woolen, cotton systems permanent non-static carpets, app. filter bags, with small percentage of filament yarn in blends high temp use applications elec resistance heating reflective uses webs compacted media	**Brunswick**
CHROMEL R	USA ductile nickel chromium heat resistant alloy readily drawable to small dia filaments available as bunched or bundle drawn yarn individual filaments 0 5 mil dia and larger, can be knit, wvn, braided by conventional machines or stretch broken and blended with other fibers for static free fabrics withstands temp of 2 000°F non-flammable to 2.500°F, space suits space re-entry decelerator devices antenna membranes see also FYREL	**Hoskins**
FYREL	USA fabric woven from multifil yarns composed of fine metal filaments such as CHROMEL-R, for flexible, high-strength, thermodurable fibrous expandable aerospace structures, also for high temperature ind uses	**Fabric Research**
GIMP	USA multifil or monofil synthetic core wrapped edge to edge with flat metallic yarns, cotton core also used for heavier wvn fabrics, braid, trim	**Metlon**
GLOWETTE	USA patented metallic yarn, textured or bulky appearance, wvn., knit uses, braids, trims	**Rich-Flex**
HOSKINS MFS	USA continuous filament stainless steel alloy yarn, any fil size and count, produced via bundle drawing, as little as 0 1 per cent woven into fabric eliminates static and repels dirt, facilitates cleaning of material, reduces dust pick-up	**Hoskins**
UNNAMED	**Japanese metal fibers developed to withstand 900°C.; melt-spinning process; 30 micron dia. fibers produced from tin, lead, tin-lead alloys, silver; experimenting with copper, 1,200°C. melting point; 5 micron fiber production possible; space suits, parachutes, nonflammable furnishings, carpets**	**Nagoya Institute**
	Swedish ultra-fine steel fibers, possible use: temperature-controlled carpets; corespun yarns with steel filament centers proposed as source of radiant heat for draperies; corespun yarns with polyester and glass fibers have been produced, with metal serving as either core or wrapper	**Unknown**

APPENDIX 4.3

CHART OF FIBER PROPERTIES, AND
ELECTRICAL RESISTANCE VS. HUMIDITY

CHART OF FIBER PROPERTIES, AND ELECTRICAL RESISTANCE VS. HUMIDITY*

Properties	Acetate Yarn		Saponified Acetate Rayon (Fortisan)	Cuprammonium Rayon	Viscose Rayon			Nylon			Zein Protein (Vicara)
								Continuous Filament		Staple	
	Regular	High elongation			Regular	Medium tenacity	High tenacity	Regular	High tenacity		
Dimensions of fibers											
Continuous length	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	—	No
Staple length, in.	15/16-7	15/16-7	Experimental	Experimental	1-6	1-6	No	—	—	1-6	1/2-6
Width, μ	11-46	11-46	3-9	About 11	10-43	8.4-43	10-15	11-42	16-43	14-43	18-41
Specific gravity	1.30-1.35	1.30-1.35	1.52	1.54	1.50-1.54	1.50-1.54	1.50-1.54	1.14	1.14	1.14	1.25
Tensile strength											
At 21°C. and 65% R.H.,[a] g./denier	1.1-1.4	1.3-1.8	7.0	1.7-2.3	1.5-2.4	2.4-3.0	3.0-4.0	4.5-6.0[r]	6.0-7.8[r]	4.0-4.8[r]	1.1-1.2
Tenacity at 21°C. and 65% R.H., p.s.i.	18,000-23,000	22,000-30,000	138,000	33,000-42,000	20,000-47,000	47,000-58,000	58,000-78,000	65,000-88,000	88,000-114,000	58,000-70,000	17,600-19,200
Wet, per cent of strength at 21°C. and 65% R.H.	60-65	50-75	85	50	44-54	56-63	55-65	85-90	85-90	85-90	80
Ultimate elongation at 21°C., 65% R.H., per cent	23-30	45-50	6	10-17	15-30	10-20	9-20	25-31[r]	15-23[r]	33-48[r]	30-45
Recovery from strain[d]											
Strain, per cent	2 20	—	2 5	5 15	2 20	2 20	2 15	2 8[p]	8[p]	—	2 8[p]
Recovery, per cent	94 23	—	82 67	48 32	82 30	82 30	82 37	100 100	100	—	100 97.8
Modulus of elasticity											
Static method,[e] 10^{10} dynes/cm.²	3.0-4.8	3.0-4.8	20.4-24.5	9.2	6.4-9.1	12.5	9.9-23.6	—	—	—	3.8[p]
Static method,[e] g./denier	26-41	26-41	152-183	85	48-68	93	74-176	About 40	—	—	32[p]
Velocity of sound method,[e] 10^{10}dynes/cm.²	6.1	6.1	—	—	11.5-13	20	20-33.8	—	—	—	—
Velocity of sound method,[e] g./denier	52	52	—	—	86-96	147	150-252	About 60	—	—	—
Stiffness,[f] average, g./denier	5.2	3.3	120	14	8.7	17	25	14-17[r]	25-32[r]	9-15[r]	2.8
Toughness index,[g] g.-cm./denier cm.	0.19	0.38	0.21	0.14	0.23	0.22	0.25	0.54-0.70[r]	0.59-0.69[r]	0.79-0.90[r]	0.18
Moisture regain at 21°C. and 65% R.H., per cent	6.3-6.5	6.3-6.5	10.0-11.5	11.0	11.5-16.6	11.5-16.6	11.5-16.6	4.0-4.5			10
Swelling in water,[h] per cent	6-30	6-30	18-26	99-134	45-82	45-82	45-82	About 2			30
Refractive index											
Epsilon[i]	1.478	1.478	1.547	1.548	1.547	1.547	1.547	1.547			—
Omega[i]	1.473	1.473	1.513	1.527	1.521	1.521	1.521	1.521			—
Dielectric constant	3.8 at 60 c. (at 0% R.H.) 5.0 at 60 c. (at 50% R.H.)		6.0 at 60 c. (at 50% R.H.)	—	—	—	—	4.0 at 1 kc. (at 18% R.H.) 20.0 at 1 kc. (wet)			—
Effect of age	Slight loss of tensile strength		Virtually none	Virtually none	Slight yellowing			None			None
Effect of heat			a	a	a						
Strength loss temperature, °F.	194-225	194-225	—	—	—			—			250
Softening temperature, °F.	397-406	397-406	—	—				Melts about at 480—sticks at 455			478-482
Effect of sunlight, prolonged exposure	Loss of tensile strength			Loss of tensile strength	Loss of tensile strength			Some loss of strength. No discoloration			Slow deterioration and loss of strength
Resistance to moths[l]	Not attacked		Not attacked	Not attacked	Not attacked			Not attacked			Resistant
Resistance to mildew[m]	Resistant		More than cotton	Attacked	Attacked			Not attacked			Resistant
Effect of strong acids	Decomposed		Decomposed	Disintegrated by hot dilute or cold concentrated	Similar to cotton			Disintegrated by concentrated mineral acids			Resistant
Effect of weak acids	Dissolved by certain weak organic acids, such as acetic		Resistant	Similar to viscose	Strength deterioration on prolonged contact or hot			Generally good resistance			Very resistant
Effect of strong alkalies	Saponified		Swelling and mercerization; loss of strength in hot concentrated	Swelling and loss of strength	Swelling and loss of strength			Virtually none			Resistant
Effect of weak alkalies	Little or no effect for short periods cold; saponification on long standing or hot		Little effect	Little effect if dilute	No effect cold; reduced strength hot or on prolonged contact			None			Very resistant
Effect or organic solvents	Insoluble in dry cleaning solvents generally; swollen or dissolved in acetone, ethyl acetate, many ketones and esters, glacial acetic acid, phenol, and some chlorinated solvents. Softened in alcohol		Resistant	Resistant	Resistant			Unaffected by dry cleaning solvents. Soluble in some phenolic compounds and in conc. (90%) formic acid			Resistant
Dyes used	Special acetate dyestuffs; selected vats and azo colors; some acid and basic dyes; pigment dyes; solvent (swelling) dyeing		Generally dyes used for cotton	Same as for viscose rayon	Acid (for tinting only); basic; direct; vat; naphthols; sulfur			Acetate and acid are preferred usually, but most other classes are also used			All usual types, including both acid wool dyes and alkaline dyes

* From M. Harris, Ed., Handbook of Textile Fibers, Textile Book Publ. Inc. (Interscience) New York (1954).

CHART OF FIBER PROPERTIES—Continued

Properties	Polyester (Dacron)		Vinyl Chloride—Vinyl Acetate (Vinyon)			Vinylidene Chloride (Saran, Velon)
	Filament	Staple[p]	Regular	High tenacity	Staple	
Dimensions of fibers						
Continuous length	Yes	—	Yes	Yes	—	Yes
Staple length, in.	—	1 up	—	—	1-5	No
Width, μ	11-28	18-25	16-18	16-18	16-18	80-1300
Specific gravity	1.38	1.38	1.33-1.36	1.33-1.36	1.33-1.36	1.68-1.75
Tensile strength						
21°C., 65% R.H., g./den	4.2-5.0[r]	3.6-4.0[r]	2.0-2.8	3.5-4.4	0.6-0.7	1.1-2.9
p.s.i.	74,000-89,000	64,000-72,000	35,000-48,000	56,000-76,000	10,000-12,000	25,000-40,000
Wet, % of 21°C., 65% R.H.	100	100	100	100	100	100
Ult. elong., 21°C., 65% R.H., %	22-30[r]	36-40[r]	14-35	16-20	10-13	20-35 (oriented)
Recovery from strain[b]						
Strain, per cent	2 8	—	2 20	—	—	—
Recovery, per cent	97 80	—	90 63	—	—	—
Modulus of elasticity						
Static method,[c] 10^10 dynes/cm.²	—	—	3.3-4.5[d]	3.3-4.5[d]	3.3-4.5[d]	0.3-1.7
g./denier	About 90[r]	—	28-30[d]	28-30[d]	26-30[d]	2-11
Velocity of sound method[e]						
10^10 dynes/cm.²	—	—	—	—	—	—
g./denier	About 120	—	—	—	—	—
Stiffness,[f] average, g./denier	14-23[r]	7-11[r]	9.6	22	5.8	16
Toughness index,[g] g.-cm./denier cm.	0.55-0.64[r]	0.76-0.96[r]	0.30	0.36	0.04	0.20
Moisture regain at 21°C. and 65% R.H., per cent	0.4		0	0	0	0
Swelling in water,[h] per cent	Virtually none		0	0	0	0
Refractive index						
Epsilon[i]	—		1.536	1.536	1.536	1.60-1.63
Omega[j]	—		1.536	1.536	1.536	1.60-1.63
Dielectric constant	3.6 at 60 c. (dry)			—		3.0-5.0 at 60 c., 1 kc., 1 mc.
Effect of age	None		None			Slight
Effect of heat						
Strength loss temperature, °F.	—		—			160-200
Softening temperature, °F.	Melts about at 480, sticks at 455		Melts at 250, shrinks at 150			Shrinks at 160-280; softens at 240-280
Effect of sunlight, prolonged exposure	Some loss of strength. No discoloration.		None			Darkens slightly
Resistance to moths[l]	Not attacked		Not attacked			Not attacked
Resistance to mildew[m]	Not attacked		Not attacked			Not attacked
Effect of strong acids	Very resistant to most mineral acids. Disintegrated by 96% sulfuric		Stable			Stable
Effect of weak acids	Virtually none		Stable			Stable
Effect of strong alkalies	Moderate resistance when cold. Disintegrated at boil		Stable			Stable to most; limited resistance to ammonia
Effect of weak alkalies	Good resistance		Stable			Stable
Effect of organic solvents	Generally unaffected. Soluble in some phenolic compounds		Soluble in ketones and some chlorinated hydrocarbons; swells and softens in ethers, esters, aromatic hydrocarbons, dioxane, propylene oxide			Swelled or softened by oxygen-bearing solvents at elev. temp.
Dyes used	Acetate, azoic, and vat with carrier or at high temperatures		Dispersed dyes with aid of certain swelling agents; solvent methods; pigment dyeing			Colored before extrusion

Properties	Vinyl Chloride-Acrylonitrile			Polyacrylonitrile (Orlon)		Acrylic		
	Staple (Dynel)	Filament (Vinyon N)				X-51		Acrilan
		Stretched	Stabilized	Filament	Staple[p]	Continuous filament	Staple	Staple
Dimensions of fibers								
Continuous length	—	Yes	Yes	Yes	—	Yes	—	—
Staple length, in.	1-1/2 to 6 or tow	—	—	—	1-6	—	1.5-4.5	1.5-6.0
Width, μ	Ratio of width to thickness: 5-6:1	8-10	10-12	18[e]	14-27[e]	—	16.5-25.0	15-20
Specific gravity	1.31	1.31	1.32	1.17	1.17	1.17	1.17	1.135
Tensile strength								
21°C., 65% R.H., g./den	3.0	3.2-4.0	3.0-3.6	4.8-5.8[r]	1.7-2.2[r]	3.4-3.9	2.5-3.5	3.5
p.s.i.	50,000	62,000-70,000	51,000-57,000	73,000-88,000	26,000-33,000	50,000-57,000	37,000-52,000	50,000
Wet, % of 21°C., 65% R.H.	100	100	100	About 95	About 95	85-95	—	90
Ult. elong., 21°C., 65% R.H., %	31	12-16	26-35	15-18[r]	25-34[r]	20-25	25-30	17.5
Recovery from strain[b]								
Strain, per cent	2[d]	3[e]	3[e]	2 8[p]	—	2 4 8[p]	2 4 8[p]	2 5 10
Recovery, per cent	97	93	77-93	97 75	—	95 84 66	92 80 70	80 80 60
Modulus of elasticity								
Static method,[c] 10^10 dynes/cm.²	4.1	10.5	4.3-6.4	—	—	4.8-5.3	1.8-3.7	—
g./denier	35	95	37-55	About 70[p]	—	53-60	21-43	—
Velocity of sound method[e]								
10^10 dynes/cm.²	—	13	—	—	—	—	—	—
g./denier	—	120	—	About 100	—	—	—	—
Stiffness,[f] average, g./denier	7.9	20-33	8.6-14	29-32[r]	5-6[r]	16	9.5	20
Toughness index,[g] g.-cm./denier cm.	0.48	0.26-0.34	0.33-0.47	About 0.43[r]	About 0.20[r]	0.42	0.35-0.58	0.22
Moisture regain at 21°C. and 65% R.H., per cent	0.5	0	—	1.0-2.0		1.5-2.0	—	1.6
Swelling in water,[h] per cent	Very slight	Very slight	Very slight	Very slight		Very slight	Very slight	About 5%
Refractive index								
Epsilon[i]	—	1.530[n]	1.530[n]	—		—	—	—
Omega[j]	—	1.530[n]	1.530[n]	—		—	—	—
Dielectric constant	—	4.2 at 60 c.	4.0 at 1 kc. (at 25°C. and 50% R.H.)	4.8 at 60 c. (dry)		—	—	—
Effect of age	Virtually none	Virtually none	Virtually none	None		Virtually none		—
Effect of heat								
Strength loss temperature, °F.	—	160	275	—		—		—
Softening temperature, °F.	Shrinks at temperatures above 240°F.	—	—	Sticks at 455-490		At 500 sticks to Parr melting point bar		Softens at 486
Effect of sunlight, prolonged exposure	Some loss of tensile strength	Darkens slightly; some loss of tensile strength		Very high resistance to sunlight deterioration		Slight loss in tensile strength		—
Resistance to moths[l]	Not attacked	Not attacked		Not attacked		Not attacked		Not attacked
Resistance to mildew[m]	Not attacked	Not attacked		Not attacked		Not attacked		Not attacked
Effect of strong acids	Gen. res., except to 25% chromic; 70% nitric; and 96% sulfuric	Generally resistant, except to 25% chromic, 70% nitric, and 96% sulfuric		Very resistant to most mineral acids. Disintegrated by 96% sulfuric		Generally resistant		Generally resistant
Effect of weak acids	Little or no effect	Little or no effect		Virtually none		Stable		Stable
Effect of strong alkalies	Resistant, except to high concentration of NaOH above 70%	Little or no effect		Moderate resistance when cold. Disintegrated at boil		Loss of strength		Color changes to red-orange
Effect of weak alkalies	Not attacked	Not attacked		Good resistance		Slight yellowing		Yellowing on prol. exp.
Effect of organic solvents	Sol. in acetone, less in higher ketones, aniline, ethylene dichloride	Generally resistant, but slightly soluble in ketones	Resistant and insoluble	Unaffected by common solvents		Unaffected by common solvents		Unaffected by common solvents
Dyes used	Selected acetate, acid, direct, some vat dyes	Acid and Acetate. Direct or some pigments can be used with proper treatment		Acid (copper technique), naphthols, basic, acetate and vat		Acetate, acid, basic, vat		Acid, acetate

CHART OF FIBER PROPERTIES—*Continued*

Properties	Polyethylene	Cotton	Silk	Wool	Glass
Dimensions of fibers					
Continuous length	Yes	No	400-1300 yards	No	Yes
Staple length, in.	No	1/2-2 1/2	Yes	1 1/2-15	Up to 18
Width, μ	250-1300	12-20	9-11	10-70	5-10
Specific gravity	0.92	1.50-1.55	1.25-1.35	1.28-1.33	2.54
Tensile strength					
At 21°C. and 65% R.H., g./denier	1.0-2.5	2.1-6.3	2.8-5.2	1.0-1.7	7.7
Tenacity at 21°C. and 65% R.H., p.s.i.	11,000-30,000	42,000-125,000	45,000-83,000	17,000-28,000	250,000-315,000
Wet, per cent of strength at 21°C. and 65% R.H.	100	110-130	75-95	76-97	99
Ultimate elongation at 65% R.H., per cent	20-60 (oriented)	3-10	13-31	20-50	2.5-3.15
Recovery from strain[b]					
Strain, per cent	5[d]	2 5	2 20	2 20	3[d]
Recovery, per cent	95	74 45	92 33	99 63	100
Modulus of elasticity					
Static method,[c] 10^{10} dynes/cm.^{2}	—	5.7-11.2	8.4-12.9	2.7-3.9	68 9
Static method,[c] g./denier	—	42-82	76-117	24-34	307
Velocity of sound method,[e] 10^{10} dynes cm.^{2}	—	—	14.4	5.1	74
Velocity of sound method,[e] g./denier	—	—	130	44	331
Stiffness,[f] average, g./denier	2-12	60	18	3.9	300
Toughness index,[g] g.-cm./denier cm.	0.3	0.15	0.44	0.25	0.13
Moisture regain at 21°C. and 65% R.H., per cent	0	8.5	11.0	17.0	0
Swelling in water,[h] per cent	0	44-49	30-41	32-38	0
Refractive index					
Epsilon[i]	—	1.580	1.591	1.556	1.55 ± 0.01
Omega[j]	—	1.533	1.538	1.547	1.55 ± 0.01
Dielectric constant	—	—	4.2 at 500 kc., 4 mc., 10 mc.	4.2 at 13 mc. 500 kc., 120 kc. 4.8 at 20 kc. 5.4 at 8 kc.	6.3 at 60 c. 6.3 at 1 mc. 5.8 at 10 mc. 5.6 at 37 mc.
Effect of age	Virtually none under normal conditions	Virtually none	Slight yellowing; slight loss of tensile	Slight yellowing; slight loss of tensile	None
Effect of heat					
Strength loss temperature, °F.	—	[k]	[k]	[k]	No loss at 475; 50% loss at 665
Softening temperature, °F.	5% shrinkage at 165°; melts at 230-250°	—	—	—	1380-1550
Effect of sunlight, prolonged exposure	Some loss of tensile for clear; much less for pigmented. No darkening	Loss of tensile; tendency for whites to yellow	Loss of tensile; affected more than cotton	Loss of tensile, dyeing affected; less affected than cotton	None
Resistance to moths[l]	Not attacked	Not attacked	May be attacked, but more resistant than wool	Attacked	Not attacked
Resistance to mildew[m]	Not attacked	Attacked, especially if sized	Not usually attacked	May be attacked; more resistant than cotton	Not attacked
Effect of strong acids	Very resistant	Disintegrated by hot dilute or cold concentrated	Dissolved	Destroyed by hot sulfuric; resistant to others	Attacked by hydrofluoric and hot phosphoric
Effect of weak acids	Very resistant	Stable if cold; strength deterioration if hot	Fairly resistant	Resistant	Stable
Effect of strong alkalies	Very resistant	Swelling and mercerization	Dissolved	Attacked	Attacked
Effect of weak alkalies	Very resistant	Little effect	Attacked if hot	Attacked if hot	Attacked if hot
Effect of organic solvents	Soluble above 160°F. in some solvents	Resistant	Resistant	Resistant	Insoluble
Dyes used	Pigmented before extrusion	Basic, direct, mordant, sulfur, vat, naphthols	Acid, basic, direct, mordant, naphthols, vat	Acid, basic, direct, mordant, vat	Resin-bonded pigments; also other dyes used on coated fibers

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* R.H. = relative humidity

[a] This compilation of the principal physical and chemical properties of the commercially important textile fibers was prepared by Daniel Frishman and Milton Harris, Harris Research Laboratories. Data appearing in the chart have been assembled from responses to a questionnaire to manufacturers, the International Critical Tables, Textile World's Synthetic Fiber Table, A.S.T.M. Standards on Textile Materials and from numerous individuals in the textile industry, as well as from measurements made in the laboratory of Harris Research Laboratories.

[b] Except as otherwise noted, all values for elastic recovery were obtained at 20°C. and 50% relative humidity; rate of loading 10 g./denier/minute; duration of action of load 20 seconds; recovery time 60 seconds.

[c] Except as otherwise noted, all values for static method were obtained under the same conditions described in footnote b.

[d] Testing conditions not reported.

[e] All values by the velocity of sound method were obtained in air-dry condition.

[f] Stiffness (resistance to deformation) is the ratio of breaking stress to breaking strain: P/E, where P is the stress in grams per denier required to produce rupture and E is the strain in centimeters per gauge centimeter at breaking stress.

[g] Toughness (the ability to absorb work), expressed as a toughness index, is the work per unit volume of material which would cause rupture if the stress-strain curve were a straight line: $PE/2$.

[h] Values pertain to cross section area increase, essentially equivalent to volumetric swelling.

[i] Index for light vibrating parallel to the long fiber axis.

[j] Index for light vibrating perpendicular to the long fiber axis.

[k] Since the effect of heat on nonthermoplastic fibers is not critical, but varies widely with temperature, duration of heating, atmosphere in which tested, previous history of fiber, etc., it is believed that the arbitrary assignment of values would be meaningless.

[l] Many materials are subject to attack by moths if they contain edible finishes.

[m] Resistance of yarns and fabrics to mildew depends in many cases upon the nature of the finishing materials used.

[n] Rate of loading 1 g./denier/minute.

[o] Stretched: rate of loading 7.5 g./denier/minute; duration of action of load 60 seconds; recovery time 60 seconds; stabilized: rate of loading 4 g./denier/minute; duration of action of load 45 seconds; recovery time 60 seconds.

[p] Measurements made on uncrimped tow.

[q] Based on circular cross sections. Orlon has "dog-bone" cross-section.

[r] Nylon and Dacron measured on Single End Scott Tester. Orlon measured on IP-4 (16 g./denier/minute). IP-4 gives higher tenacities than Scott.

[s] Recovery against no load, samples loaded and load released immediately, recovery within 60 seconds (70°F., 65% R.H.).

[t] Instron Tester, 10% per minute rate of elongation (70°F., 72% R.H.).

[u] $n_D/27$°C. = 1.580 obtained on pressed disk of Vinyon N resin. Birefringence could not be detected in this manner.

[v] Filament was stretched the indicated amount and released immediately; recovery measured 60 seconds after release.

CHART OF FIBER PROPERTIES—*Continued*

DU PONT TEFLON TETRAFLUOROETHYLENE FIBER

A. Tabulation of Filament Yarn Properties

Specific gravity	2.3
Tensile strength*	42,700 lbs. per sq. in.
Tenacity*	1.45 g. per denier
Elongation*	21.2% at break
Wet strength*	Equal to dry strength
Wet elongation*	75.3% of dry
Dry, loop, and knot strength*	80.8% and 78% respectively of straight tenacity
Wet, loop, and knot elongation*	98.4% and 72.4% respectively of straight elongation
Modulus*	Low (9 g. per denier)
Zero strength temperature	590°F.
Gel temperature	621°F.
Decomposition temperature	750°F.
High temperature stability	Resists dimensional change—can be heatset—good flex and abrasion—nonbrittle
Possible useful temperature environment	400-525°F.
Chemical stability	Only affected by fluorine gas and by chlorine trifluoride at high temperature and pressure and by molten-alkali metals
Flammability	Nonflammable but melts with decomposition
Moisture absorption	Zero
Wettability	Most nonwettable fiber known
Adhesiveness	Fiber is slippery—few materials stick to it with any degree of adhesion
Coefficient of friction	Lowest of any fiber known. Boiled off yarn, dynamic .25, static .20
Electrical properties	Excellent
Dyeability	Very poor
Color	Tan to brown—can be bleached white in strong oxidizing mineral acid

* Instron tests

B. Room Temperature Properties of Fibers from Teflon after Exposure to Hot, Extremely Corrosive Liquids

Conditions	Tenacity, G./Denier	Elongation, %	Denier
Control	1.9	31	8
Concentrated H_2SO_4, 5 minutes bleaching at 660°F.	1.1	96	12
Concentrated H_2SO_4 + HNO_3, 4 hours at 330°F.	1.2	65	11
25% caustic, 4 hours at 240°F.	1.4	88	11

On exposure to elevated temperatures, Teflon fiber shrinks moderately. However, this shrinkage does not continue with continued exposure, and fabrics may be satisfactorily pre-shrunk by brief treatment above the intended service temperature.

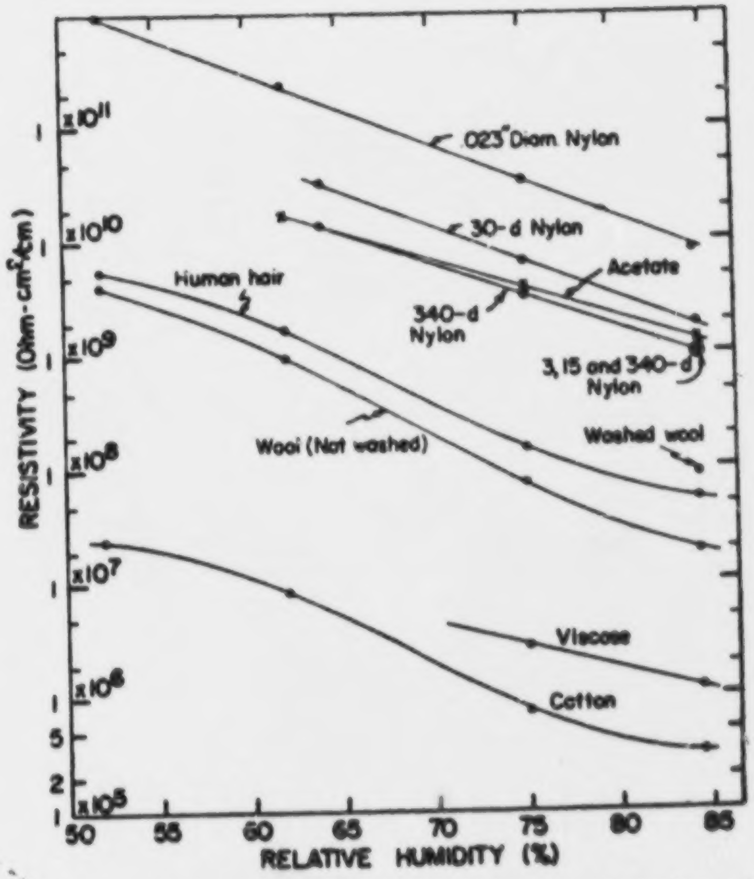
C. High Temperature Properties of Teflon Fiber

Test Temperature, °F	Breaking Load at Test, Lbs./In. of Fabric	Tenacity, G./Denier*	Breaking Elongation, %
70	90.0	1.40	94
200	35.0	0.30	50
300	16.0	0.17	37
400	13.3	0.15	26
450	12.3	0.14	32
475	11.7	0.13	23
500	—	0.10†	—
590	Zero strength temperature	0.10†	—
620	Transition temperature	(Solid gel)	—

News Release, E. I. du Pont de Nemours & Co., Inc., May, 1954.

* Calculated from fabric strength, except where indicated.

† Measured on filaments using zero strength tester.



Resistivity of single fibers at 30°C. as a function of relative humidity. (Hersh, S. P. and Montgomery, D. J.: Textile Research J., **22**: 805, 1952.)

APPENDIX 4.4

1969 SUPPLIERS LIST
FILTER FABRICS AND RELATED MATERIALS
PLUS
SUPPLIER BROCHURES

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1969 SUPPLIERS LIST

FILTER FABRICS AND RELATED MATERIALS

Part 1.

This list resulted from a survey in 1969 by GCA Technology Division as a portion of the Fabric Filter Systems Survey. Included are manufacturers of filter fabrics, sewers and suppliers of the finished filter elements (see Part 2 of the Appendix), and manufacturers of fibers used in fabric filtration. These firms are representative of those supplying the fabric filtration industry. A complete listing of textile fiber sources is contained in "Guidebook to Man-Made Textile Fibers and Textured Yarns of the World" by A. A. Dembeck, The United Piece Dye Works, 111 West 40th St., New York, New York, 3rd Ed. (1969).

Footnotes to the following Table:

(1) Processor and supplier of fabrics; capability for controlled porosities.

(2) Supplier of filter system components other than fabrics.

(3) Also polyallomer.

(4) No recent information received.

(5) Also needle punch synthetic.

(6) Also vinyon, or vinylidene chloride, PVC.

(7) Silicone fiber lubricants.

(8) Lofted nonwoven.

(9) Also paper.

(10) Asbestos paper for corrugated air filters.

(11) Also "filter media".

(12) Teflon or silicone for coated glass fabrics.

(13) Graphite fiber, and/or carbon fiber.

(14) Metal fiber woven separately or with asbestos, glass, or synthetics.

(15) Sintered fiber metals.

(16) Also triacetate.

1969 Suppliers List: Filter Fabrics and Related Materials	Yarns or fibers	Woven fabrics	Woven felts	Non-woven felts	Other	Bags	Tubes	Envelopes	Other	Asbestos	Cotton	Rayon	Polyester, e.g. Dacron R	Modacrylic, e.g. Dynel R	Glass	Nylon	Nomex R Nylon	Acrylic e.g., Orlon R	Orlon R-Wool	Polyethylene	Polypropylene	Vinal	Teflon R	Wool	Metal	Ceramic	Other	Comments
Albany Felt Company		x	x	x		-All types--					x		x	x	x	x	x	x	x	x	x		x	x				
American Combining Corp.		x			(1)						x				x		Synthetics											
American Viscose Div. FMC Corp.	x											x	x														(6)	
American Enka	x															x												
Brunswick Corporation	x	x					x			(14)					(14)										x			(14)
Burlington Glass Fabrics Co.		x																										
The Carborundum Company	x	x													Kynol											x		
Celanese Fibers Marketing Co.	x															x												(16)
Chemstrand Corp.	x															x		x										
Clark-Schwebel Fiber Glass Corp.		x													x													(12)
Coast Mfg. Div., Hexcel Corp.		x				x	x								x													
Crane Cochrane		x			(2)																							
W. W. Criswell Co.						All types				x	x		x	x	x	x	x	x		x	x		x	x				
Deering-Milliken, Inc.		x				x	x				x	x																
Dow Chemical Co.	x																	x				x						
E. I. du Pont de Nemours	x			x									x			x	x		x				x					
Eastman Chemical Products, Inc.													x	x						x	x						(3)	
Edward H. Best & Company		x	x			-All types-					x		x	x		x	x	x		x	x			x				
Exeter Manufacturing Co.		x													x													(4)
Fabrics Specialties						-All types-				-- Nearly All types - - - - - - - - -																		
The Felters Co.				x	(5)								x			x	x	x	x		x			x				
Filter Media Products, Pangborn						x	x	x		- - Nearly all types - - - - - - - -																		
Filtration Fabrics Div, Ametek						x	x				x		x	x	x	x	x	x		x	x		x				(6)	
GAF Corp., Ind. Prod. Div.				x									x	x	x	x	x	x			x		x	x				

Manufacturer	Yarns or fibers	Woven fabrics	Woven felts	Non-woven felts	Other	Bags	Tubes	Envelopes	Other	Asbestos	Cotton	Rayon	Polyester, e.g. Dacron^{R}	Modacrylic, e.g. Dynel^{R}	Glass	Nylon	Nomex^{R} Nylon	Acrylic e.g., Orlon^{R}	Orlon^{R}-Wool	Polyethylene	Polypropylene	Vinal	Teflon^{R}	Wool	Metal	Ceramic	Other	Comments
General Filter Co.		x					x																					
General Electric Co.					(7)															x								
Hitco		x																								x		
Huyck Metals Co.				(15)																					x			
Industrial Rayon		x										x				x												
C.O. Jelliff Corp.		x																							x			
J. P. Stevens & Co., Inc.		x											x	x	x	x	x				x							
Johnson March						x	x	x		-	-	Nearly all types						-	-	-	-	-	-	-				
The Kendall Co.				x									x	x		x	x				x							
Kressilk Products, Inc.		x				x							x			x	x			x	x		x		x			
Lennox Industries, Inc.		x																										
Libby Owens Ford Glass Fiber Co.	x														x													
Menardi and Company		x	x	x		All types					x		x		x	x	x	x			x		x					
Microtron Corp.				x	(8)	All types																						
Mil-An Mfg. Corp.						x	x	x		x	x		x	x	x	x	x	x	x	x	x		x	x				(9)
Modern Dust Bag Co., Inc.						x	x				x		x	x	x	x	x	x	x		x			x				(9)
National Filter Media Corp.		x				All types																						
Nicolet Industries, Inc.									(10)	x																		
Owens/Corning Fiberglas Corp.	x				(11)										x													
Pallflex Products Corp.					(12)																							
Polymer Research Corp.					(2)																							
PPG Industries		x													x													
Schwartz Mfg. Co.						All Types					x		x		x	x	x	x			x		x	x				(2)
Troy Mills, Inc.					x								x			x	x	x			x							

Manufacturer	Yarns or fibers	Woven fabrics	Woven felts	Non-woven felts	Other	Bags	Tubes	Envelopes	Other	Asbestos	Cotton	Rayon	Polyester, e.g. Dacron^{R}	Modacrylic, e.g. Dynel^{R}	Glass	Nylon	Nomex^{R} Nylon	Acrylic e.g., Orlon^{R}	Orlon^{R}-Wool	Polyethylene	Polypropylene	Vinal	Teflon^{R}	Wool	Metal	Ceramic	Other	Comments
Uniglass Industries		x													x													
Union Carbide Corp.	x																			x							(13)	
Uniroyal Inc.		x								x				x							x							
West Point Pepperell		x		x							x	x	x	x	x	x		x										(4)
Western Felt Works			x	x																								
Whitehouse Products Inc.		x				x	x	x			x		x			x	x	x			x			x				

Albany Felt Company
1373 Broadway
Albany, New York 11201

American Combining Corporation
72-36 Burchell Avenue
Arverne, New York 11692

American Viscose Corporation
FMC Corporation
350 Fifth Avenue
New York, New York 10018

American Enka
Rocky Hill
Connecticut 06067

Brunswick Corporation
Technical Prods. Division
132 Second Avenue
Needham Heights, Mass. 02194

Burlington Glass Fabrics Company
New York
New York 10018

Carborundum Company
Buffalo Avenue
Niagara Falls, New York 14303

Celanese Fibers Marketing Company
Barclay Downs Drive
Charlotte, North Carolina 28209

Chemstrand Corporation
350 Fifth Avenue
New York, New York 10018

Clark-Schwebel Fiber Glass Corporation
Post Office Box 408
Anderson, South Carolina 29621

Coast Mfg. Div., Hexel Corporation
11711 Dublin Boulevard
Dublin, California 94566

Crane-Cochrane
Post Office Box 191
King of Prussia, Pennsylvania 19406

W. W. Criswell Company
800 Industrial Highway
Post Office Drawer 32
Riverton, New Jersey 08077

Deering, Milliken, Inc.
1045 Sixth Avenue
New York, New York 10018

Dow Chemical Company
Midland
Michigan 48640

E. I. Dupont de Nemours and Company
Industrial Fabrics Section
902 Wilmington Trust Building
Wilmington, Delaware 19898

Eastman Chemical Products Inc.
Kingsport, Tennessee 37662

Edward H. Best and Company
210 Lincoln Street
Boston, Massachusetts 02111

Exeter Mfg. Company
Industrial Glass Cloth Division
1451 Broadway
New York, New York 10018

Fabrics Specialties, Inc.
1362 W. Sixth Street
Cleveland, Ohio 44113

The Felters Company
22 West Street
Millbury, Massachusetts 01527

Filter Media Products Division
The Pangborn Corporation
Hagerstown, Maryland 21740

Filtration Fabrics
A Division of Ametek, Inc.
552 Twelfth Avenue
East Moline, Illinois 61244

GAF Corporation
Industrial Products Division
140 West 51 Street
New York, New York 10020

General Filter Company
Post Office Box 350
Ames, Iowa 50010

General Electric Company
Silicone Products Department
Waterford, New York 12188

Hitco
1600 W. 135th Street
Gardena, California 90249

Huyck Metals
Milford
Connecticut 06460

IRC Fibers Division
Midland - Ross Corporation
Painesville, Ohio 44077

Jeliff Corporation
354 Pequot Road
Southport, Connecticut 06490

J. P. Stevens & Company, Inc.
1460 Braodway
New York, New York 10036

Johnson March Corporation
3018 Market Street
Philadelphia, Pennsylvania 19104

The Kendall Company
95 West Street
Walpole, Massachusetts 02081

Kressilk Products Inc.
420 Saw Mill River Road
Elmsford, New York 10523

Lennox Industries, Inc.
Marshalltown
Iowa 50158

Libby-Owens Ford Glass Company
811 Madison Avenue
Toledo, Ohio 43624

Menardi and Company
1201 W. Francisco Street
Torrance, California 90502

Microtron Corporation
Post Office Box 15335
Charlotte, North Carolina 28210

MIL-AN Mfg. Corporation
29 Crescent Street
Brooklyn, New York 11208

Modern Dust Bag Company, Inc.
111 E. Railroad Avenue
West Haverstraw, New York 10993

Nat. Filter Media Corporation
Moorestown, New Jersey 08057

Nicolet Industries, Inc.
Wissahickon Avenue
Ambler, Pennsylvania 19002

Owens/Corning Fiberglass Corporation
Fiberglass Tower, One Levis Square
Toledo, Ohio 43601

Pallfelx Products Corporation
Kennedy Drive
Putnam, Connecticut 06260

Polymer Research Corporation
Brooklyn
New York 11234

PPG Industries
(Formerly Pittsburgh Plate Glass)
One Gateway Center
Pittsburgh, Pennsylvania 15222

Schwartz Manufacturing Company
Two Rivers
Wisconsin 54241

Troy Mills, Inc.
18 Monadnock Street
Troy, New Hampshire 03465

Uniglass Industries
1407 Broadway
New York, New York 10018

Union Carbide Corporation
270 Park Avenue
New York, New York 10017

Uni-Royal Inc.
350 Columbia Road
Winnsbow, South Carolina 29180

West Point Pepperell
111 West 40th Street
New York, New York 10018

Western Felt Works
4115 Ogden Avenue
Chicago, Illinois 60623

Whitehouse Products Inc.
360 Furman Street
Brooklyn, New York 11201

Part 2 of Appendix 4.4

DATA SHEET AND BROCHURE OF A TYPICAL FILTER ELEMENT SUPPLIER*

DUST COLLECTOR TUBE DATA SHEET

Company Name ________________________________
Address ________________________________
____
____

1. Name of dust collector system ________________________________.
2. Measurements of tube or bag (blueprint preferred) ________________________________.
3. Material used (Acrylic/Orlon, Polyester/Dacron, Nylon, Nomex, Rayon, Polypropylene, Glass, Wool, Silk, Cotton -- other) ________________
4. Weave (Plain, Twill, Satin, Felt, etc.) ________________________.
5. Weight per square yard, thickness, thread count ________________________________.
6. Permeability (C.F.M./sq. ft. at diff. 0.5 inches of water) __________.
7. Treatment (Graphite, Teflon, Silicone, etc.) ____________________.
8. Maximum operating temperature ________________________________.
9. Is there dry ____________ or moist ____________ air? (check one).
10. Are there mineral __________ or organic __________ acids? (check one). (specify) ________________________________.
11. Are there alkalies? ________________________________.
12. Are there oxidizing agents? ________________________________.
13. Are there solvents? ________________________________.
14. Steel bands or other retaining rings or ropes ____________________.
15. Estimated annual usage __________ Quantity per order ____________.

Please mail the completed data sheet, together with applicable blueprints, drawings, samples or other information.

---

* Courtesy of Bemis Company, Inc.

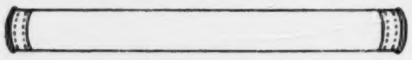
STANDARD REPLACEMENT BAGS AND TUBES

(Pictured are some of the many standard replacement bags and tubes made by Bemis)

Count on Bemis to supply the replacement bags and tubes necessary to keep your dust collecting system operation at peak efficiency. Bemis can supply any type of bag you require.

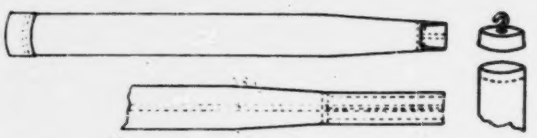
Following are descriptions of standard bags and tubes for some of the widely used dust collecting systems. Yours may operate more efficiently with types of materials offered by Bemis. Let us consult with you on your specific requirements.

AMERICAN AIR FILTER



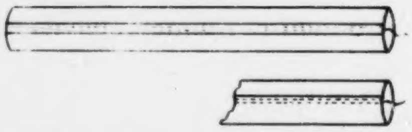
Basic construction: Open both ends. Endless extension coil spring ring inserted in each cuff.

AMERICAN WHEELABRATOR



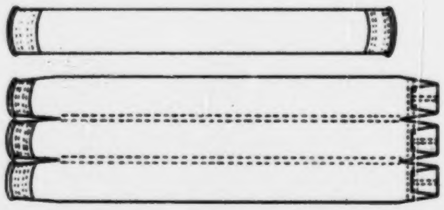
Basic construction: Hem top, strap top (12" to 14" in length), or open top for plug. Steel band spring ring in cuff.

DAY-HERSEY-MIKRO



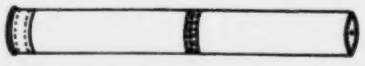
Basic construction: Day and Hersey tubes are open at both ends. Mikro tubes may have both ends open or have a disc sewn in one end with the other end raw. Butt seam with tape. Available with or without special tin-coated copper static wire.

DRACCO



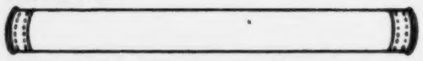
Basic construction: Tubes or bags (V-top, triple-hook top or regular top).

FULLER



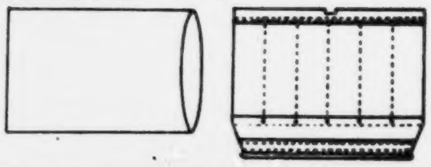
Basic construction: One open end with a rope inserted in a double cuff. Other end is closed by sewing in a disc with a ½" diameter hole in center. Metal ring sewn to outside in center of tube.

NORBLO



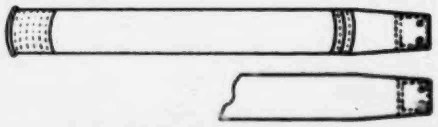
Basic construction: Both ends open with a rope inserted in a double cuff. Widths of cuff differ according to application.

PANGBORN



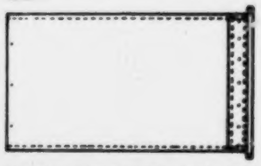
Basic construction: Single-compartment or multi-compartment bag. Close cell sponge neoprene cord in bottom hem.

PARSONS



Basic construction: Open at one end with either a rope in the cuff or an endless extension coil spring ring inserted. Other end closed with grommets in each corner. Available with or without an oblong metal ring sewn to the outside, near the closed end, and with or without tin-coated copper static wire.

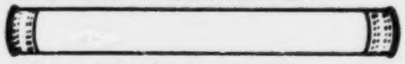
SLY



Basic construction: A. EE or ED — 36" x 43½". A single-compartment bag with a 33½" metal rod inserted in each hem. Three holes in bottom of bag, seven holes in hem and one hole in each ear.

B. Resist-O-Wear — 34½" x 46¾". A three-compartment bag similar in construction to Type EE and ED except for addition of a false bottom for inserting a mullion and vertical stitching for compartments. Patented by W. W. Sly Manufacturing Co., which has licensed Bemis.

WESTERN PRECIPITATOR



Basic construction: Both ends open with fiberglass or asbestos rope inserted in double cuff, or fiberglass drawcord in one cuff.

(From a Bemis Company, Inc. brochure.)

APPENDIX 5.1

MANUFACTURER'S GUIDELINES TO THE SELECTION OF AIR/CLOTH RATIO FOR FOUR TYPES OF FABRIC COLLECTORS

(1) Shaking Bag Collector

(2) Glass Cloth Collector usually employing reverse flow plus collapse cleaning

(3) Reverse Jet Collector

(4) Reverse Pulse Collector

(1) GUIDE TO SHAKING BAG AEROTURN SELECTION*

A

4/1 RATIO		3/1 RATIO		2.5/1 RATIO		2/1 RATIO		1.5/1 RATIO	
MATERIAL	OPERATION	MATERIAL	OPERATION	MATERIAL	OPERATION	MATERIAL	OPERATION	MATERIAL	OPERATION
Cardboard	1	Asbestos	1, 7. 8	Alumina	2, 3, 4, 5, 6	Ammonium Phosphate Pert.	2, 3, 4, 5, 6, 7	Activated Charcoal	2, 4, 5, 6, 7
Feeds	2, 3, 4, 5, 6, 7	Aluminum Dust	1, 7. 8	Carbon Black	4, 5, 6, 7	Diatomaceous Earth	4, 5, 6, 7	Carbon Black	11, 14
Flour	2, 3, 4, 5, 6, 7	Fibrous Mat'l.	1, 4, 7, 8	Cement	3, 4, 5, 6, 7	Dry Petrochem.	2, 3, 4, 5, 6, 7, 14	Detergents	2, 4, 5, 6, 7
Grain	2, 3, 4, 5, 6, 7	Cellulose Mat'l.	1, 4, 7, 8	Coke	2, 3, 5, 6	Dyes	2, 3, 4, 5, 6, 7	Metal Fumes, Oxides and other Solid Dispersed Products	10, 11
Leather Dust	1, 7, 8	Gypsum	1, 3, 5, 6, 7	Ceramic Pigm.	4, 5, 6, 7	Fly Ash	10		
Tobacco	1, 4, 6, 7	Lime (Hydrated)	2, 4, 6, 7	Clay & Brick Dust	2, 4, 6, 12	Metal Powders	2, 3, 4, 5, 6, 7, 14		
Supply Air	13	Perlite	2, 4, 5, 6	Coal	2, 3, 6, 7, 12	Plastics	2, 3, 4, 5, 6, 7. 14		
Wood, Dust, Chips	1, 6, 7	Rubber Chem.	4, 5, 6, 7, 8	Kaolin	4, 5, 7	Resins	2, 3, 4, 5, 6, 7, 14		
		Salt	2, 3, 4, 5, 6, 7	Limestone	2, 3, 4, 5, 6, 7	Silicates	2, 3, 4, 5, 6, 7, 14		
		Sand *	4, 5, 6, 7, 9, 15	Rock, Ore Dust	2, 3, 4, 5, 6, 7	Starch	6, 7		
		Iron Scale	1, 7, 8	Silica	2, 3, 4, 5, 6, 7	Soaps	3, 4, 5, 6, 7		
		Soda Ash	4, 6, 7	Sugar	3, 4, 5, 6, 7				
		Talc	3, 4, 5, 6, 7						
		Machining Operation	1, 8						

CUTTING – 1
CRUSHING – 2
PULVERIZING – 3
MIXING – 4
SCREENING – 5
STORAGE – 6
CONVEYING – 7
GRINDING – 8
SHAKEOUT – 9
FURNACE FUME – 10
REACTION FUME – 11
DUMPING – 12
INTAKE CLEANING – 13
PROCESS – 14
BLASTING – 15

B

FINENESS FACTOR

MICRON SIZE	FACTOR
> 100	1.2
50 - 100	1.1
10 - 50 *	1.0
3 - 10	.9
1 - 3	.8
< 1	.7

C

DUST LOAD FACTOR

Loading GR. CU. FT.	Factor
1 - 3	1.2
4 - 8	1.0
9 - 17	.95
18 - 40	.90
> 40	.85

This information constitutes a guide for commonly encountered situations and should not be considered a "hard-and-fast" rule. Air-to-cloth ratios are dependent on dust loading, size distribution, particle shape and "cohesiveness" of the deposited dust. These conditions must be evaluated for each application. The longer the interval between bag cleaning the lower the air-to-cloth ratio must be. Finely-divided, uniformly sized particles generally form more dense filter cakes and require lower air-to-cloth ratios than when larger particles are interspersed with the fines. Sticky, oily particles, regardless of shape or size, form dense filter cakes and require lower air-to-cloth ratios.

EXAMPLE: Foundry shakeout unit handling 26000 CFM and collecting 3500 #/ hr. of sand. The particle distribution shows 90% greater than 10 microns. The air is to exhaust to room in winter, to atmosphere in summer.

$$3500 \ \#/_{HR} \div 60 \ \frac{MIN.}{HR} \div 26000 \ \frac{CU. FT.}{MIN.} \times 7000 \ ^{GR}/_{\#} = 15.7 \ \frac{GR}{CU. FT.}$$

*Chart A = 3/1 ratio, Chart B = Factor 1.0, Chart C = .95; 3 x 1 x .95 = 2.9 air to cloth ratio. 26000 ÷ 2.9 = 9,000 sq. ft. Use size 1-600 Shaking Bag Aeroturn with 9,420 sq. ft. of filter area.

---

* From Buffalo Forge Company Bulletin AHD-29.

(2) how to size a Dracco glass-cloth dust collector*

The size of a Dracco glass-cloth dust collector is determined primarily by the volume of gas to be handled and the air to cloth ratio as illustrated in Table B on this page. Select the air to cloth ratio best suited to a particular application and use the following formula to obtain the net cloth area.

$$\frac{\text{air volume}}{\text{air cloth ratio}} = \text{net cloth area}$$

After determining the net cloth area, refer to Table C on this page for available standard sizes. Table C gives the total net cloth area for four through twelve compartments, housing 60 through 120 bags per compartment.

Refer to dimension Tables A_1 and A_2 on page 13 (for suction or pressure type units) to determine ground area required. **Note:** For any given net cloth area, there are several choices for unit size. The actual selection will depend upon the total cost, ground area available, and maximum allowable fluctuation of system resistance. Generally, the overall cost of a collector decreases as fewer compartments are used. This is true until a point is reached, beyond which the individual compartments have increased in size sufficiently to require additional supports.

For an immediate estimate, contact a Fuller representative.

Table B:

Sizing data for typical applications

Ratio	
1:1-1.3:1	**Carbon Black Generator Furnace and Channel Black.**
1.5:1-1.8:1	**Electric Furnace and Ferro Alloy Furnaces; Most Metallurgical Fume.**
1.8:1-2:1	**Cement and Lime Kilns, Wet and Dry Process; Open Hearth and Oxygen-Lanced Open Hearth Furnaces and Smelters.**
2:1-2.3:1	**Clinker Coolers, Refractory Kilns and Furnaces; Coal-Fired Boilers (Power Plant).**
2.3:1-2.5:1	**Special Application Only.**

Fuller offers a choice of methods of dislodging accumulated dust from glass-cloth bags. Each method is designed to minimize damage to delicate glass fibers and extend bag life. Application and space requirements generally determine the method to be used. Reverse air cleaning, employing bag collapse and inflation, is recommended for a majority of glass-cloth dust collector applications. The SONIC CLEANING and BOTTOM JET methods are recommended to supplement reverse air cleaning where dust particles are difficult to dislodge or where higher air-to-cloth ratios are desired.

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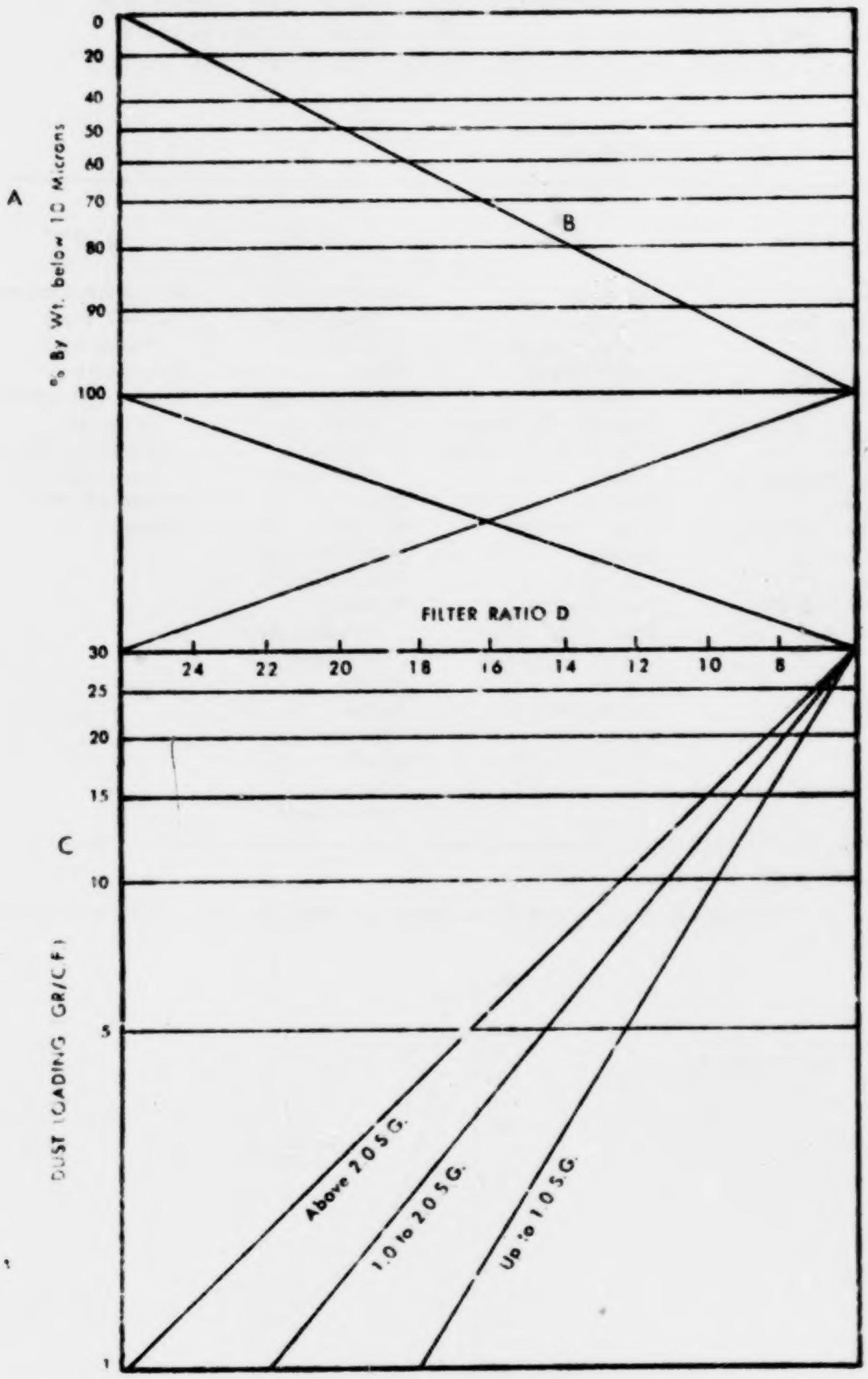
* From Fuller Company Bulletin DCB-1B.

(3) AIR/CLOTH RATIO SELECTION FOR REVERSE JET EQUIPMENT*



HOW TO USE

In order to select Filter Ratio, three conditions pertaining to your specific dust collection job are needed. They are:

a. The approximate percentage, by weight, of dust particles 10 microns or smaller.

b. Dust content of the air entering the Aeroturn Collector expressed in terms of grains (7000 per lb.) per cubic foot. Use average or normal values for both dust and air quantities.

c. Specific gravity of the material to be collected.

1. From appropriate point on vertical scale A draw horizontal line intersecting sloping line B.

2. From appropriate point on vertical scale C draw horizontal line intersecting the sloping line which represents the proper specific gravity range for the material to be collected.

3. Now, draw a straight line between points selected in steps 1 and 2 above. The intersection of this line with horizontal scale D gives the Filter Ratio. This value may now be used in the Size Selection Chart, on the next page, to determine the Aeroturn Dust Collectors applicable to your requirement.

---

* From Buffalo Forge Co. Bulletin AP650.

(2) how to size a Dracco glass-cloth dust collector*

The size of a Dracco glass-cloth dust collector is determined primarily by the volume of gas to be handled and the air to cloth ratio as illustrated in Table B on this page. Select the air to cloth ratio best suited to a particular application and use the following formula to obtain the net cloth area.

$$\frac{\text{air volume}}{\text{air cloth ratio}} = \text{net cloth area}$$

After determining the net cloth area, refer to Table C on this page for available standard sizes. Table C gives the total net cloth area for four through twelve compartments, housing 60 through 120 bags per compartment.

Refer to dimension Tables A_1 and A_2 on page 13 (for suction or pressure type units) to determine ground area required. **Note:** For any given net cloth area, there are several choices for unit size. The actual selection will depend upon the total cost, ground area available, and maximum allowable fluctuation of system resistance. Generally, the overall cost of a collector decreases as fewer compartments are used. This is true until a point is reached, beyond which the individual compartments have increased in size sufficiently to require additional supports.

For an immediate estimate, contact a Fuller representative.

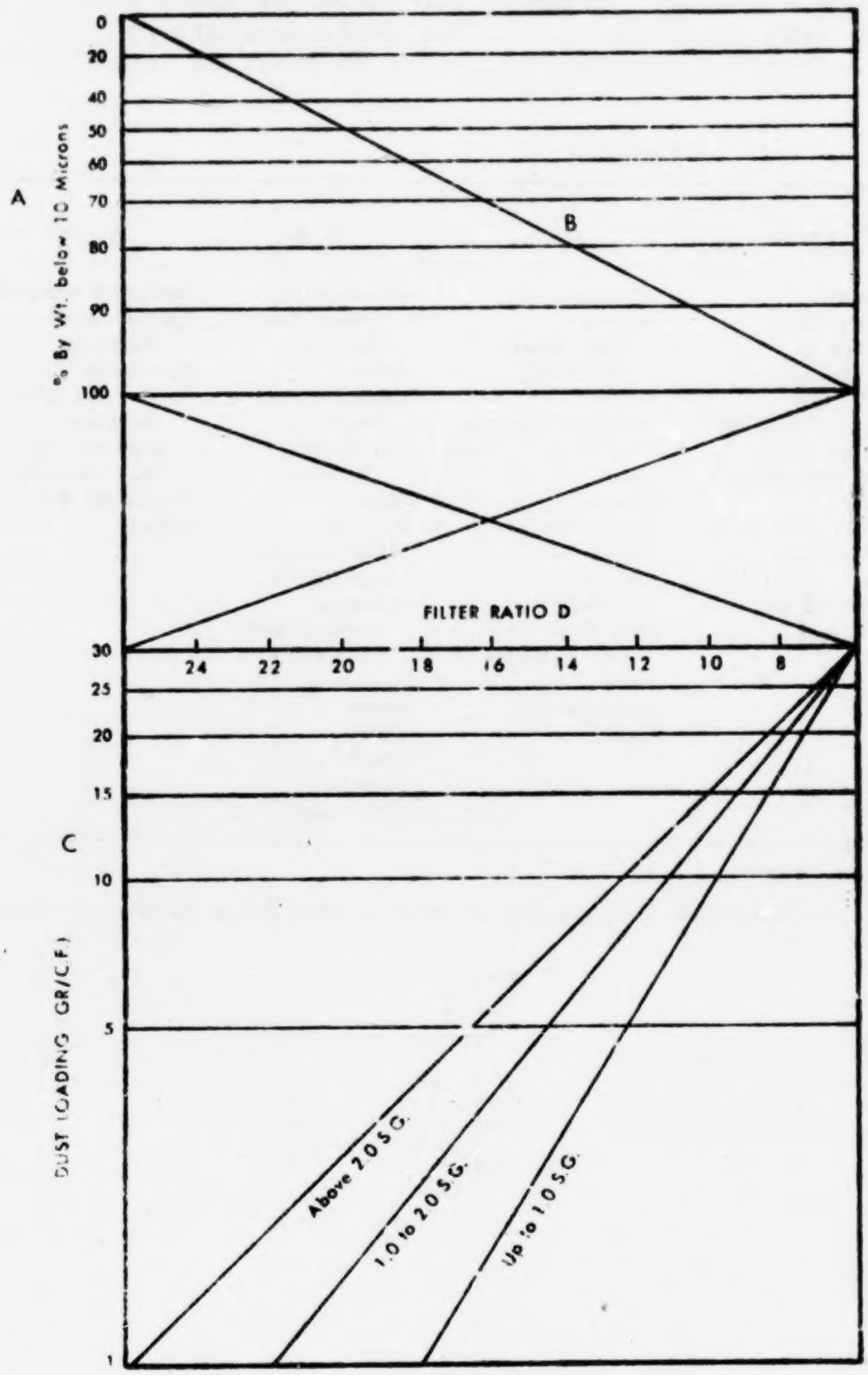
Table B:
Sizing data for typical applications

Ratio	
1:1-1.3:1	Carbon Black Generator Furnace and Channel Black.
1.5:1-1.8:1	Electric Furnace and Ferro Alloy Furnaces; Most Metallurgical Fume.
1.8:1-2:1	Cement and Lime Kilns, Wet and Dry Process; Open Hearth and Oxygen-Lanced Open Hearth Furnaces and Smelters.
2:1-2.3:1	Clinker Coolers, Refractory Kilns and Furnaces; Coal-Fired Boilers (Power Plant).
2.3:1-2.5:1	Special Application Only.

Fuller offers a choice of methods of dislodging accumulated dust from glass-cloth bags. Each method is designed to minimize damage to delicate glass fibers and extend bag life. Application and space requirements generally determine the method to be used. Reverse air cleaning, employing bag collapse and inflation, is recommended for a majority of glass-cloth dust collector applications. The SONIC CLEANING and BOTTOM JET methods are recommended to supplement reverse air cleaning where dust particles are difficult to dislodge or where higher air-to-cloth ratios are desired.

* From Fuller Company Bulletin DCB-1B.

(3) AIR/CLOTH RATIO SELECTION FOR REVERSE JET EQUIPMENT*



HOW TO USE

In order to select Filter Ratio, three conditions pertaining to your specific dust collection job are needed. They are:

a. The approximate percentage, by weight, of dust particles 10 microns or smaller.

b. Dust content of the air entering the Aeroturn Collector expressed in terms of grains (7000 per lb.) per cubic foot. Use average or normal values for both dust and air quantities.

c. Specific gravity of the material to be collected.

1. From appropriate point on vertical scale A draw horizontal line intersecting sloping line B.

2. From appropriate point on vertical scale C draw horizontal line intersecting the sloping line which represents the proper specific gravity range for the material to be collected.

3. Now, draw a straight line between points selected in steps 1 and 2 above. The intersection of this line with horizontal scale D gives the Filter Ratio. This value may now be used in the Size Selection Chart, on the next page, to determine the Aeroturn Dust Collectors applicable to your requirement.

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* From Buffalo Forge Co. Bulletin AP650.

(4) AIR/CLOTH RATIO SELECTION FOR REVERSE PULSE EQUIPMENT*

"...The application of this Guide is to high performance, high filter rate (or velocity) collectors which usually use a felt media combined with frequent and thorough cleaning. Examples are pulse jet types and blow ring (i.e., reverse jet) style units......The Guide consists of five factors which are multiplied together to arrive at a filter rate."

TABLE A

Multiplier **A**	*15**	*12*	*10*	*9.0*	*6.0***
MATERIALS	Cake Mix Cardboard Dust Cocoa Feeds Flour Grain Leather Dust Sawdust Tobacco	Asbestos Buffing Dust Fibrous & Cellulosic Material Foundry Shakeout Gypsum Lime (Hydrated) Perlite Rubber Chemicals Salt Sand Sandblast Dust Soda Ash Talc	Alumina Aspirin Carbon Black (Finished) Cement Ceramic Pigments Clay & Brick Dusts Coal Flourspar Gum, Natural Kaolin Limestone Perchlorates Rock Dust, Ores and Minerals Silica Sorbic Acid Sugar	Ammonium Phosphate-Fertilizer Coke Diatomaceous Earth Dry Petro-chemicals Dyes Fly Ash Metal Powder Metal Oxides Pigments, Metallic and Synthetic Plastics Resins Silicates Starch Stearates Tannic Acid	Activated Carbon Carbon Black (Molecular) Detergents Fumes and other dispersed products direct from reactions Powdered Milk Soaps

*In general physically and chemically stable materials.

**Also includes those solids that are unstable in their physical or chemical state due to hygroscopic nature, sublimation and/or polymerization.

TABLE B

APPLICATION	*FACTOR B*
NUISANCE VENTING Relief of transfer points, conveyors, packing stations, etc.	1.0
PRODUCT COLLECTION Air conveying-venting mills flash driers classifiers, etc.	0.9
PROCESS GAS FILTERATION Spray driers, kilns, reactors, etc.	0.8

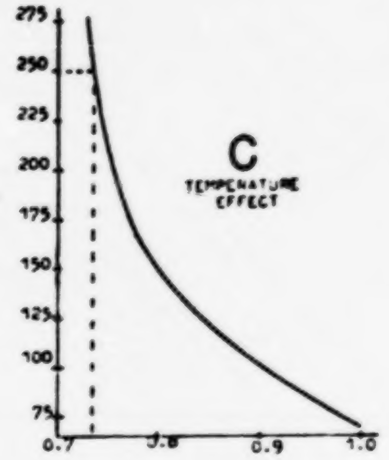

TABLE C shows temperature effect as related to amount of cloth fabric required.

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* From R. F. Frey and T. V. Reinauer, Pulverizing Machinery Co., "New Filter Rate Guide", Air Engineering, 30 (April 1964).

TABLE D

FINENESS	FACTOR D
Over 100 micron	1.2
50 to 100 micron	1.1
10 to 50 micron	1.0
3 to 10 micron	0.9
Under 3 micron	0.8

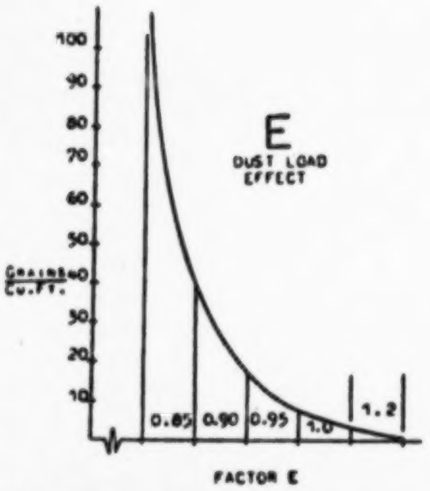

TABLE E shows dust load effect, and shows typical performance curve of a pulse jet or blow ring collector.

A. *This factor is obtained from Table A.* It is a function of the material itself, combining many of the items that effect filtration. Laboratory test can determine this factor, but field experience on a given material is far superior since longer operating periods are sometimes necessary to arrive at true equilibrium. The normal datum used is operation at ambient temperature with average 10-50 micron dust and approximately 10 grains/cu. ft. load from a nuisance class application.

B. *An application factor.* Obviously, process operation with attendant upsets must be treated differently than simple venting. This factor attempts to classify common applications.

C. *The temperature effect.* Experience has shown more cloth is required with increased temperature approximately as shown on Curve "C". The explanation is probably a gas viscosity increase with temperature. This is eventually counteracted by reduced density, hence the curve is asymptotic to a value of approximately 0.7 at 250° or more.

D. *The fineness factor.* This obvious factor needs little explanation. It is sometimes difficult to divorce fineness from the character of the material. Fume in general has a low "A" factor because of fineness.

E. *The dust load curve.* This curve is the typical performance curve of a pulse jet or blow ring collector plotted at a constant differential pressure. It usually becomes asymptotic to a given cfm/Sq. Ft. which means that above a certain loading, normally in excess of 100 grains/Cu. Ft., a given collector can handle more material without lowering cfm/Sq. Ft. The probable reason for this is the fact that the air becomes saturated with dust, much as it can become saturated with water and simply cannot hold more, thus the bag surfaces receive a saturation-limited rate of accumulation per unit time.

EXAMPLE:

Given: 36000 acfm effluent from a spray drier
Plastic Resin Dust 20 to 30 μ average size (fines present to 0.5 μ) 1500 lbs/Hr.

Required: Filter Rate

$$\text{Grains/Ft.}^3 = \frac{1500}{60} \times \frac{7000}{36000} = 4.9$$

Solution:
A = 9.0
B = 0.8
C = 0.78
D = 1.0
E = 1.0

Filter Ratio = 9.0 x 0.8 x 0.78 x 1.0 x 1.0 = 5.6 cfm/Sq. ft.

Approximately 6500 Sq. Ft. MIKRO-PULSAIRE required.

APPENDIX 6.1

HOPPER CONFIGURATION BIBLIOGRAPHY

HOPPER CONFIGURATION BIBLIOGRAPHY

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APPENDIX 6.3

DEVELOPMENT OF OPERATING EQUATIONS FOR THE MULTICOMPARTMENT COLLECTOR

In Chapters 6 and 2 the dependency of filter drag on pressure drop across the filter and on filtering velocity is discussed in detail for a single compartment. It is shown there that the single compartment drag is predictable if the residual drag and the specific resistance of the additional deposited material can be predetermined. Since this statement applies to any single compartment, the same is true for the compartments of a multicompartment collector. However, additional equations are required to combine the separate compartments into an operating whole. Furthermore, each compartment affects the performance of the other compartments by taking more or less than its average share of the distributed flow, depending on whether its instantaneous drag is more or less than its average drag. Consequently the operating equations for a multicompartment collector, although fundamentally the same as for a single compartment, appear to be much more complex.

In a multicompartmented baghouse, the individual compartments may be considered resistant elements arranged in parallel with a common driving force, the filter pressure differential. The resulting volumetric flow rate is comparable to current flow in amperes. For an electrical system of parallel resistances, $(R_1, R_2 \ldots, R_n)$ the resistance (R) of the system may be calculated from the equations:

$$\frac{1}{R} = \sum \frac{1}{R_i}, \quad i = 1 \ldots n \qquad 6.3.1$$

Likewise, the effective drag of a baghouse (S) may be expressed as a function of the drag of each compartment $(S_1, S_2, \ldots S_n)$ according to the equation:

$$\frac{A_t}{S} = \sum \frac{A_i}{S_i}, \quad i = 1 \ldots n \qquad 6.3.2$$

where A_t is the total filter area of the house, and $A_1, A_2, \ldots A_n$ are the filter areas of the compartments.

The generation of differences in filter drag within a multicompartmented baghouse may be illustrated by considering an ideal situation in which total flow, particulate load and size distribution, and gas temperature are constant, and variations in pressure losses to and from the individual compartments are negligible. When an installation is first put on stream under these conditions, the drag will be essentially the same in all of the various compartments as governed by the permeability of the fabric. However, when a cleaned compartment is subsequently used for filtration, its drag will be less than that of the other compartments so that deposition of dust in this unit will proceed faster than in the other compartments. Subsequent filtration will alter the velocity pattern since, for any small increment of time, the amount of dust deposited in each compartment will be proportional to the average velocity in that compartment at that time. Hence, the drag of the cleaned unit will increase more rapidly than the drag of the other units, resulting in a rapid decrease in average velocity through this compartment. Eventually an equilibrium distribution of filter drag will develop.

With reference to Figure 6.53 of Volume 1, at time t_a a freshly cleaned compartment comes on stream, at t_b one compartment is at its terminal condition and taken out of service for cleaning, and at t_c the compartment is returned to service. Considering the filter areas of all compartments as equal, for the overall system the condition at t_c is the same as at t_a. Thus, the process is cyclic. Utilizing equation 6.8 of Volume 1, it can be shown that at time t_b

$$\frac{n}{S_{e_2}} = \frac{1}{S_t} + \sum \frac{1}{S} \qquad 6.3.3$$

where S_{e_2} is the drag of the house at time t_b, S_t is the terminal drag of the compartment to be cleaned, and $\sum \frac{1}{S}$ represents the combined drag for the remainder of the compartments.*

As soon as the compartment is removed for cleaning,

$$\frac{n-1}{S_{e_2}} = \sum \frac{1}{S} \qquad 6.3.4$$

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[*] G. W. Walsh and P. W. Spaite, Characterization of Industrial Fabric Filters, Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio, presented at the ASME Winter Annual Meeting, New York (December 1960).

assuming the combined drag for the remaining compartments has not changed. S_{e_3} is the drag of the house after the compartment to be cleaned has been taken off-stream. (There may be added resistance to flow if the velocity rise in the remaining compartments causes deposit resistance increase.)

Equations 6.3.3 and 6.3.4 may be combined to give:

$$\frac{n}{S_{e_2}} - \frac{n-1}{S_{e_3}} = \frac{1}{S_t} \qquad 6.3.5$$

which is readily solved for the terminal drag of a compartment.

A similar treatment may be applied to solve for the residual drag of a compartment (S_r) in which case the final equation is:

$$\frac{n}{S_{e_1}} - \frac{n-1}{S_{e_4}} = \frac{1}{S_r} \qquad 6.3.6$$

where S_{e_4} and S_{e_1} are the effective drags of the baghouse at times t_b and t_c when the house pressure differential is Δp_4 and Δp_1, respectively.

The residual velocity, u_{f_r}, may be calculated from S_{e_1} and S_r as follows:

$$S_{e_1} = \frac{\Delta p_1}{u_f} \qquad 6.3.7$$

and

$$S_r = \frac{\Delta p_1}{u_{f_r}} \qquad 6.3.8$$

therefore,

$$\frac{u_{f_r}}{u_f} = \frac{S_{e_1}}{S_r} \qquad 6.3.9$$

where u_f is the average (total fabric) velocity with all compartments in service.

The previous discussions have been limited to performance of an ideal baghouse. Variations from ideal conditions do not detract from the utility of using filter drag as a property of the system to facilitate quantitative evaluation of a baghouse. Due to the nature of the fans used on most installations, a variation in flow rate occurs as the drag of a baghouse changes. An analysis of flow rate with cycle time is, therefore, a critical step in the characterization technique. For a fabric filter system with a large number of units, operating with short cycle times, the flow variations will be minimized. When the number of compartments is small, the changes for significant flow differences are great, and they may completely obscure the true performance as reflected in pressure differential data alone.

To illustrate this, consider the pressure differential curves for a four-compartment fabric filter system collecting fume from an electric-arc furnace, as shown in Figure 6.3.1. Two curves are shown on this figure; the solid curve represents average pressure differentials recorded in the field; the dotted curve represents the pressure differentials that would have existed if flow and v's were constant. It can be seen that there are material differences between respective values. The first curve tends to indicate very little change in pressure drop with time, while the second shows the opposite.

To obtain the curve representing constant flow conditions, it was necessary to correlate the volume of gas flow with cycle time, as shown in Figure 6.3.2. Filter drag values were then calculated and these values used to obtain the pressure differentials that would exist if flow had been maintained constant.

Entrance and exit losses to compartments also introduce slight errors in characterization since the pressure differential across such elements is not directly proportional to flow. Therefore, when a compartment is put on stream and a redistribution of gas takes place, the resistance of the inlet and outlet elements of those compartments continually in service will change to a small degree. Where the number of compartments is large (say 6 or greater) and where frequent cleaning is employed, the gas volume to be redistributed will be relatively small and the changes negligible.

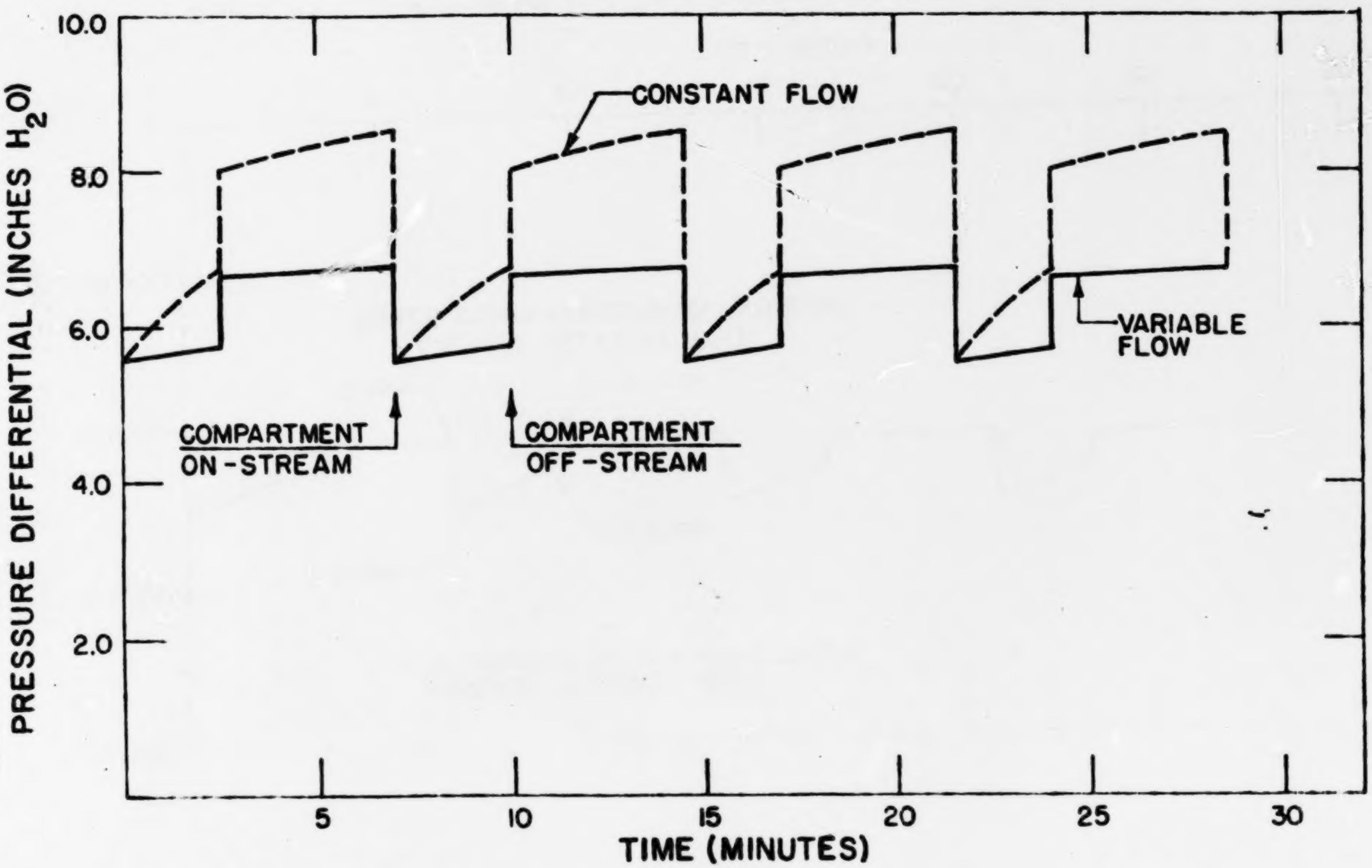

Figure 6.3.1 Effect of Flow Variation on Pressure Differential Curve

(From Walsh and Spaite, _ibid._)

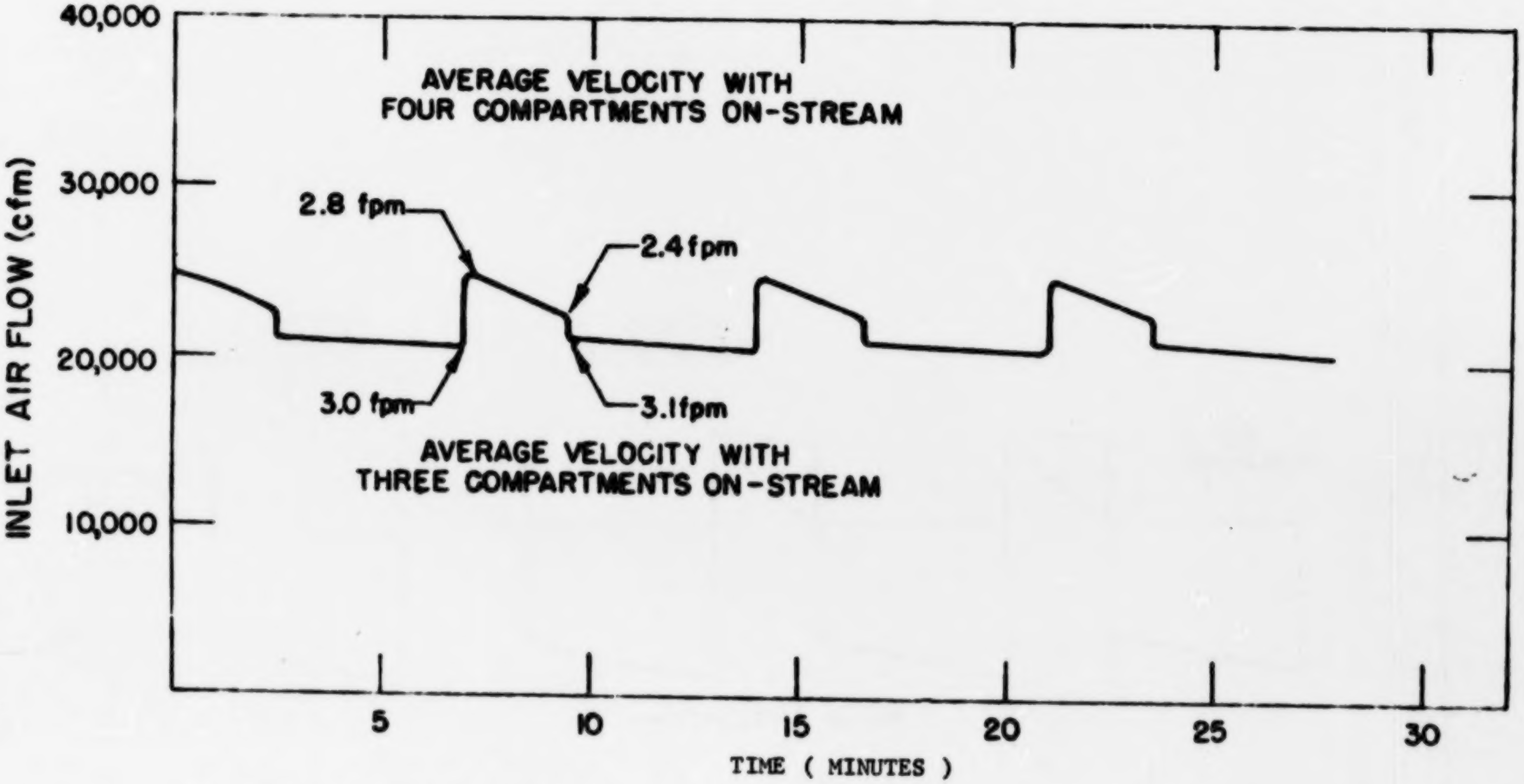

Figure 6.3.2 Flow Variation with Cycle Time for Four Compartment Baghouse

(From Walsh and Spaite, ibid).

In the unusual situations where a more exact value of the residual drag of the filter media in the compartment brought on stream is desired, it can be calculated from the maximum velocity at the start of filtration, as previously defined, and from additional pressure differentials measured from the clean air side to the dirty air side of the filter media in the individual compartment.

Robinson, et al,* have presented an analytical model for pressure drop performance of the 3-compartment fabric filter pilot unit (500 cfm) shown in Figure 6.4.7 of Volume 1. Flows through individual compartments followed the patterns shown in Figure 6.3.3. Part I shows the flow distribution when compartment 1 comes back on stream after cleaning. This compartment, because of its low filter drag, carries the greatest portion of the total flow. In the same filtering interval, compartments 2 and 3 exhibit greater drag and experience less flow because of dust filtered since their last cleaning. Curves in Parts 2 and 3 show all compartments in the second and third filtering intervals after compartment 1 has been cleaned. The three curves marked compartment 1 show the flow distribution for this compartment during one complete filtration cycle.

The three curves in a single part of the figure represent the flow through three compartments in a single interval. They also represent the flow conditions that would exist in any one compartment during three successive filtering intervals. Put another way, the three curves of Part 1, which represent flow through compartment 1 immediately after cleaning, flow through compartment 2 in the second interval after cleaning, and flow through compartment 3 in the third interval after cleaning, are identical to the curves representing flow through compartment 1 in the first, second, and third successive filtration intervals.

Analysis of such curves using experimental data from the pilot unit established that the time-flow curves for all compartments could be fitted to exponential equations of the form:

$$Q = at^x \qquad 6.3.10$$

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*J. W. Robinson, R. E. Harrington, and P. W. Spaite, A New Method for Analysis of Multicompartmented Fabric Filtration, Robert A. Taft Sanitary Engineering Center, U.S. Public Health Service, Cincinnati, Ohio, for presentation at the AIChE 58th National Meeting, Dallas, Texas (February 1966).

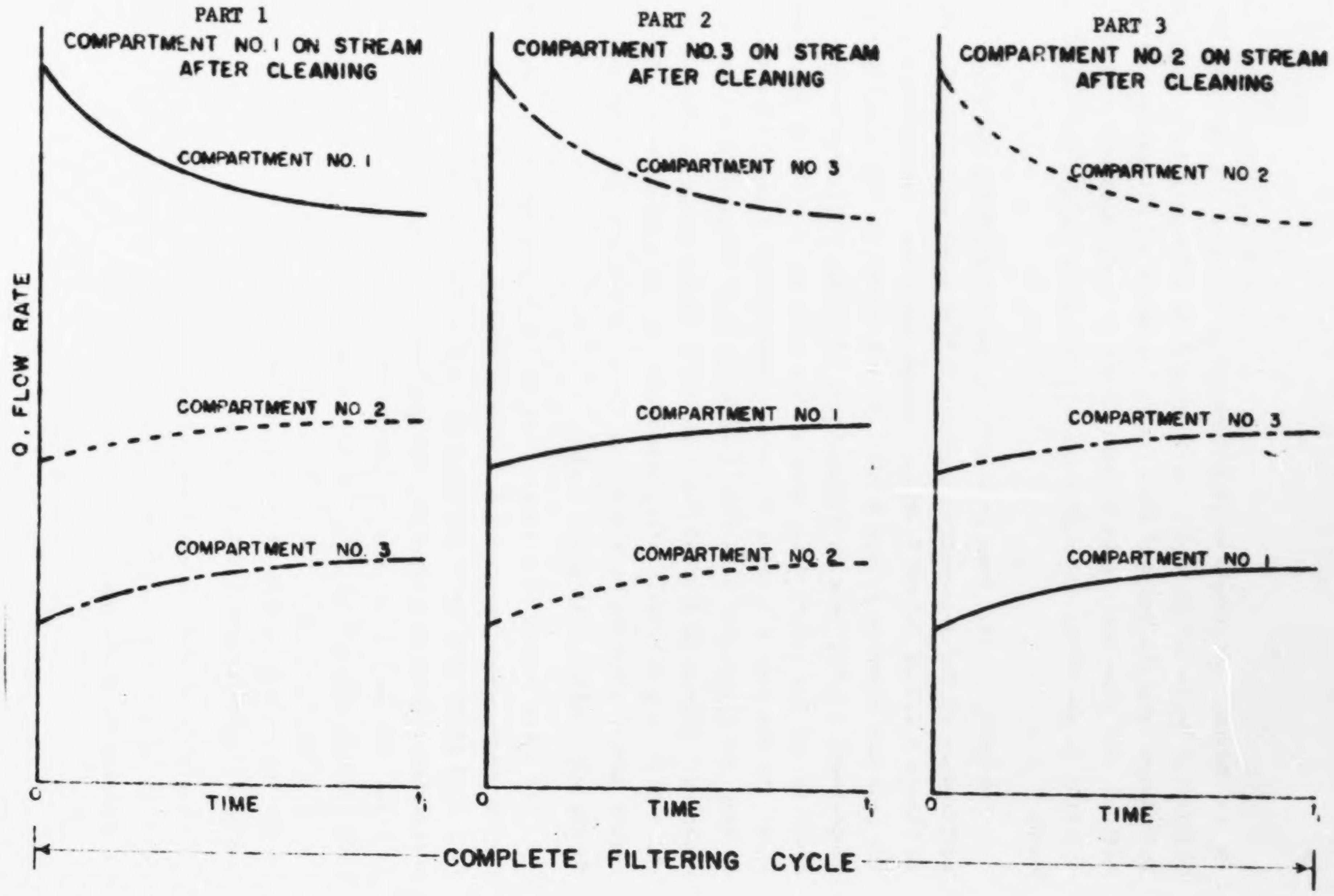

Figure 6.3.3 Three Compartment Baghouse with Intermittent Cleaning

(From Robinson, et al, ibid).

where coefficient (a) and exponent (x) were essentially constant over the time of filtration. Because the dust accumulation rate is proportional to Q, integration of these equations enabled an empirical determination of deposit weight and thus of drag for individual compartments, as functions of (a), (x), and time. Using considerations similar to those discussed above, these drags could be combined to give the overall drag of the system. The values of (a) and (x) were different for each of the three intervals shown in Figure 6.3.3. Furthermore, each value although constant over the interval of filtration was empirically determined to depend on inlet concentration, flow rate, and interval duration as well as on two to four empirical constants. Once all these constants were determined the overall drag of the system could be determined as a function of time. However, these constants may vary from system to system, with the number of compartments, etc.

Thus, this particular method of analysis as a ready and general method remains to be demonstrated.

APPENDIX 6.4

FIELD PERFORMANCE DATA FOR SELECTED FABRIC FILTER INSTALLATIONS

Within the fabric filtration literature are numerous references to specific installations of filter equipment, each in a specific industrial plant location. Most of these references do not provide enough technical data to be useful to persons having similar application interests, and only contribute to the statistics of filter distribution and use. Some references however do provide a wealth of technical detail, and these are tabulated with primary data in the following pages. These literature references are supplemented with data gained during the GCA survey of representative filter installations. It will be recognized that many of the reported values for efficiency, pressure differential, etc. are transitory and further, may be based on the opinions of the personnel interviewed, rather than tests.

Explanation of Selected Column Headings:

Efficiency: Collection efficiency (percent)
Concentration: Inlet concentration of dust to the filter (grains/ft^3)
K-value: Specific resistance of the deposit, in. H_2O/(lb./ft^2-fpm)
Continuous: Is the process served by the filter operated continually?
Steady: White the process operates, is the gas flow approximately constant?
Pressure Differential: Average pressure across the filter
Cloth Name: Gl = glass   Va = various fabrics reported
Wo = wool   Da = Dacron^R Dy = Dynel^R
Co = cotton   Ny = nylon   Or = Orlon^R
Nom= Nomex^R Polyp = polypropylene
Filter Type: I = dust collected on the inside of the filter element
O = collected on the outside
U = upward flow through the filter house
D = downward flow
Cleaning Mechanism: RFC = reverse flow accompanied by flexural collapse
V = vibration
RF = reverse flow with little or no flexure
Sh = shake
RP = reverse pulse
RJ = reverse jet ring
Son = sonic cleaning
Cloth problems: see footnote table
Baghouse problems: see footnote table
Costs: apply to the overall system
References: see footnote bibliography

FIELD PERFORMANCE DATA FOR SELECTED FABRIC FILTER INSTALLATIONS

Category, Dust name, Process	Efficiency	DUST: Ave. particle size	Concentration	K-value	GAS: Inlet Temperature	Corrosive?	Continuous?	Steady?	Gas flow	Air/cloth ratio	Pressure difference	CLOTH: Cloth name	Cloth life, yrs.	Filter type	Cleaning mechanism	Cloth probs.	Baghouse Problems	COSTS: Installed ($/CFM)	Operating	Maintenance	Total annual	References
Combustion																						
Coal Ash-Boiler		20	1.9	8.5	270	-	N	Y	20	2.3	5.6	Gl	-	I.D	RFC							1,2,3,4
Coal Ash-Boiler	99.5					-	Y	Y	1.	(2.5)	4	Gl	(2)		RFC,V	7						5,6
Coal Ash-Boiler				(7)		-	Y	Y	10	(3.)	(2.5)	Gl		I.U	RF							PC^2
Coal Ash-Lab		10	3.0	(8)	Amb	N	N	-	.032	4.0	(3)	Va		I.D	Sh							7,8,9,10,4
Coal Ash-Lab	99.9	15	Va.		Amb	N	Y	Y	.50	8.	(5)	Wo		O.U	RF							11
Oil Ash-Boiler	99.9				300	Y	Y	Y	2.5	7.7	3.2	Gl		I.U,D	RFC							12,13,14
Oil Ash-Boiler			.013	(4.7)	285	Y	Y	Y	820 K	6.5	5.7	Gl	1.	I.U	RFC	8,7		2.34			.46	15,16,14
Municipal Incin.	99.8	Va.	.46	25.	(500)	-	Y	N	.375	5	4	Gl	>1	O.U	RF							17,18,PC
Municipal Incin.	96.5	Va.	.33	180.	480	Y	N	N	14	2.5	3.6	Gl	>2	I.U	RFC		19	2.01				PC
Refuse Incin.	99.6		.25		410	-	N	N	5.3	(10)	3.7											19
Food and Feed																						
Flour Mill	99.9	10	14	4.3	110	N	Y	Y	8.4	8.6	4.5	Wo	1.5	I.D	RJ	1		2.36	.20	.07	.39	PC
Inorganic Chemicals																						
Lime Kiln			7.5	9.	500	N	Y	Y	140.	2.3	5	Gl	1.2	I.U	RFC,FP	3,5		7.94	.12	.26		PC
Lime Kiln		5	8.6		(450)					2.1		Gl	2.					1.80	(.06)	(.14)		20
Dolomite (MgO) Milling		40	7.0	(670.)	150	N	Y	N	3.3	0.7	3	Da	1.	I.U	RF	2,3,4.5,6	1		.07	.43		PC
Alumina Handling		100	9 K	0.2	Amb	N	N	Y	0.11	1.9	1.8	Da	.25	O.U	RF	8,7	6	50.		10.00		21,PC
Hypochlorite Mfgr.		50	2.3	15	Amb	-	Y	-	10.	3.3	3	Dy	.6	I.U	Sh	3,7	5,21		.07	.39		PC
Chromium Salts									26	2.4	5	Wo		I.D	RJ							22
Organic Chemicals																						
Carbon Black Mfgr	99.5		15	56	425	-	Y	Y	43.	1.6	7.5	Gl	1.	I.U	RF	1	13,11		.18	.33		23,24,PC
Carbon Black Mfgr.	99.99		25	38	375	-	Y	Y	18.	1.1	5.8	Gl	2.	I.D.	RF,Sh	3,5	19,11,18					23,24 PC
PVA Handling	99^+	3	.05	(25)	Amb	Y	Y	N	14.	10.	(5)	Wo	.33	I.D	RF	7,8,13	10		.12	.22		PC
Misc. Resin Handling		5	3.	8.0	Amb	N	Y	N	4.	2.7	3	Co	1.	I.U	Sh	1,7,12	5,21		.07	.26		PC
Non Metallic Minerals																						
Cement Kiln-Dry	99.8	10	10.		510	-	-	-	300			Gl										25
Cement Kiln-Dry(?)	99.6	10	2.8		510	-	Y	Y	300	2.0		Gl	2.0	I.U	RFC			3.33				26
Cement Kiln-Wet	99.9	10	12.		320	-	-	-	146			Gl										25
Cement Kiln-Wet	99.5				600	-	Y	Y	140	2.0	(7)	Gl	3.0		RFC			1.16	.14	.17		27
Cement Kiln-Wet					550	-	Y	Y	95	2.1	3	Gl	(2)	I.U	RFC							28
Cement Kiln-Dry					650	-	Y	Y			2.5	Gl	(2)	I.U	RFC	2,14	5					28
Cement Kiln-Wet(?)	99^+	(15)	.5	12	525	-	Y	Y	343	1.5	4	Gl	1	I.U	RFC	3						PC
Cement Milling			(5.)	70	325	-	Y	-	10	1.8	2.5	Co	1	I.U	Sh	1,12,6	21			.26		PC
Cement Loading		10			Amb	N	N	Y	2.2	1.8		Co	3	Env.	RF	7	6			.21		PC
Cement Bagging					Amb	N	N	N	8.3	2.5	2.5	Co	.75	Env.	RJ	1	19,20	1.30	.08	.27		PC
Cement - General		10			Var	-	-	-	(.03)	3.0	3.	Var.	Var.	I.U	Sh	1						29,30
Stucco Classifying		5			220	N	N	Y	6	7.5	2.7	Da	2.5	O.U	RF	3,5			.11			PC
Stucco Conveying		40			200	-	N	Y	10			Co	3	Env.	RF		21					31
Stucco Board Trim		Var	.7	9	140	N	N	N	7	3.4		Co	3	I.U	Sh	10,7	21,17			.26		PC
Glass Frit Smelter			.3		185	-	-	-	9.3	2.2		Da	(3)									31
Glass Mfgr. Handling		100			Amb	-	Y	N	.17	2.3	3	Co	.33	O.U	Sh	10						PC
Abrasive Mfgr.					Amb	-	-	-	Var	2.5	3	Co	1		Sh	1,3	16,17,14					PC
Asphalt Rock Proc.	99.9		27		400	-	-	-	41.	7.5		Ny	(2)	O.U	RF							32
Asphalt Rock Proc.	100	5	1.6	(1.7)	150	N	-	-	30.	9.0	3.5	Wo		I.D	RJ							33
Asphalt Rock Proc.		(20)			Amb	N	N	N	10			Co	(3)	I.U	Sh		21					PC

FIELD PERFORMANCE DATA (continued)

Category, Dust name, Process	Efficiency	DUST: Ave. particle size, μ	Concentration	K-value	GAS: Inlet temperature	Corrosive?	Continuous?	Steady?	Gas flow	Air/Cloth ratio	Pressure difference	CLOTH: Cloth name	Cloth life, yrs.	Filter type	Cleaning mechanism	Cloth problems	Baghouse problems	COSTS: ($/CFM) Installed	Operating	Maintenance	Total Annual	References
Iron and Steel																						
Foundry Cupola			.70	120.	450	-	N	N	120	2.1	7.5	Gl	0.3	I.U	Sh	3,7	8,21	(7.30)	.53	.94		34,35,36,PC
Foundry Cupola		20	(2)		275	-	N	N				Or			Sh							35,36,37
Electric Furnace	99	1	.33	715.	225	N	Y	N	60	1.43	6	Da	(1.5)	I.U	RFC		21	>3.90	.15	(.17)		PC
Electric F,O.L.			2.3		275	N	Y	N	340.	2.5		Da		I.U	RFC							37
Electric F,O.L.	75	.5	.18		140	-	N	N	110	4.	4	Var	1.5		RF,RP	5,7		2.62	.45	.17	.86	38
Electric Furnace	97	(1)	2.7		400	-	Y	N	80	1.5		Gl	2.5	I.U	RF	3,14	21					39,40,PC
Electric Furnace		1	.76	45	110	-	N	N	115	2.8	1.9	Or	2.5	I.U	Sh	3	21,1			.09		41,PC
Electric F,O.L.			.5	(50)	150				170	1.9	2.4	Gl		I.U	RFC							42
Electric Furnace	98^+		.5	(49)	140				26	1.9	3.5	Or		I.-	Sh							43
Electric F,O.L. Shop	99		.09	(100)	175				700	(3)	(6)	Or		I.U	Sh			2.86				44,45
Electric F,O.L. Shop		10	.54	65	195	-	Y	N	525	1.95	5.8	Gl	4	I.U	RFC	14	21	4.85	.26	.19		PC
Iron and Steel (Contd.)																		7.3			(1.84)	46,47,48
B.O.F(-Pompey)	99.9	(.5)	2.2		215	-	-	N	46	1.8	(8.5)	(Da)	>4		RF,Sh							48
B.O.F.-Reladling		75	.5	(120)		-	N	N	1	4.5	(6)	Co,Da			Sh			(4.0)				PC
B.O.F.-Reladling		80	.5	233	200	-	N	N	100	2.5	8.2	Da	(1)	I.U	Sh	3	5	(5.20)		.20		49,50,39.24
Open Hearth	99.5	(5)	.8	35	430	-	N	N	(100)	2.0	3.3	Gl	(2)	I.U	RFC,Son	2	6,21					PC
Sinter Drop Off		Var	1.9	12	285	-	-	-	240	2.3	5.0	Gl	2	I.U	RFC	1	10,20			.52		PC
Shake out,Shot Blast			7	3.	Amb	N	N	N	12	5.0	(6)	Co	1.6	I.D	RJ	4,11						51
Perlite Expansion		Var			225	-	-	-		3.0		Da			Sh							
Non-Ferrous Metals																	19					52
Zinc-Conc. Roasting	99^+	8	4.	50	450	Y	Y	-	.8	3.0	7.5	Gl	(1.5)		RFC	14,7,5.3	18					53
Zinc-Sintering		(50)	7.8	7	200	-	Y	-	90.	2.3	3.5	Or	(1.5)	I.U	RFC,Sh	7,3						54
Zinc-Fuming Kiln					400	Y	Y	-	100.	3.0		Nom	2		Sh	12,3						55
Zinc-Muffle Fnce.					180	-	-	-	30	1.8		Or			Sh							56,57
Zinc-Galvanizing		2	(.2)	180	Amb	N	-	N	36	2.7	4	Co	7.5		Sh	7						58,59
Copper-Primary Smelt.			1.7	65	450	-	-	-	200	.9	9	Gl	2	I.U	Sh,RFC	14,2,3						60,61
Copper-"Flammofen"	99.8		1		400	-	-	-	4	(2.7)	6.5	Gl	2	I.U	RFC							62,63
Copper-Secondary Smelt.			.75		250	-	-	-	300	1.5		Or		I.U	Sh			3.60		1.65		64,PC
Copper-Secondary Smelt.		(1)	8.	40	600	-	Y	N	3.6	.6	3	Gl	1	I.U	Sh	4				1.14		65,PC
Copper-Converter	99^+	(100)	1.8	(15)	350	Y	N	N	150	1.3	7	Nom	3.5	I.U	Sh	4,1	21,8			1.38		PC
Copper-Blast Fnce.	99^+	(1)	1.2	18	375	-	Y	-	190	1.25	9	Gl	.67	I.U	Sh	3,7,13		5.20		1.15		66,67
Lead Blast Fnce.	99.8	(1)	3		225	-	-	-	260	2.4	6	Or	(1.5)					5.70		1.48		66,67,64
Lead Slag Fuming	99.7	(1)	4		250	-	-	-	195	3.5	6	Or	(1.5)					11.00		.24		PC
Lead Blast Fnce.	99^+	(1)	2.3	57	275	-	-	-	25	1	2	Da	1.75	I.U	RF,Sh	13						68
Aluminum Spray Disposal		(2)	100	.7	(400)	-	-	-	.002	3	1.7	Gl			RF	7						69
Uranium Processes	99.99	(1)	14			-	-	-	60	17	7	Wo	3wks		RJ	6	11				.35	107,331
Beryllium Sinter	Hi	(5)	.0008		250	-	-	-	40	20		Polyp	2	I.D	RP	1,7						83
Miscellaneous																						
Fibrous Grinding		Var.	.7	5	Amb	N	N	N	10	6		Co	.1		Sh	1,18	17,21			45		PC
Motor Room	94.				Amb	N	Y	Y	48	5.9		Co	9.	I.U	Sh							PC
Ultrafiltration, Beryllium Plnt					Amb	N	-	-	162	6.0		Or			Sh		21					175,72

FOOTNOTE TABLE

REPORTED CAUSES OF BAG FAILURE AND BAGHOUSE SYSTEM DIFFICULTIES

No.	Descriptions of Bag Failure
1	Interstitial D/F abrasion
2	Chafe
3	Flexure wear
4	Pinholes
5	Seams fail
6	Tension
7	Blinding
8	Cage, wire, ring, abrasion wear
9	Sewing
10	Tear at top
11	Cleaning carriage, bag wear
12	Heat
13	Hard Cementitious deposits, cracks

No.	Descriptions of Baghouse Difficulties
1	Bags too loose
2	Seams blow
3	Threads abrade
4	Holes, pinholes near bot., shot holes
5	Chafe on housing
6	Piping, elbows abrade
7	Flexure wear, abrasion
8	Burn holes, burn baghouse
9	Blinding
10	Cage, ring wear
11	Unable to enter to maintain or service during operation
12	Hole detection or effluent monitor
13	Ring fatigue
14	Hood inlet control poor
15	Cloth abrasion
16	Seals around cloth-metal collars
17	Screw conveyors, hoppers sticking and holdup
18	Seeper
19	Condensation
20	Internal mechanism wear
21	External mechanism wear, timer, shaker, fan, brgs, doors, seals, wall failures
22	Hygroscopicity

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APPENDIX 7.1

CHECK LIST OF ITEMS FOR CAPITAL COST ESTIMATES

CHECK LIST OF ITEMS FOR CAPITAL COST ESTIMATES*

- Land:
  - Surveys
  - Fees
  - Property cost
- Site development:
  - Site clearing
  - Grading
  - Roads, access and on-site
  - Walkways
  - Railroads
  - Fence
  - Parking areas
  - Other paved areas
  - Wharves and piers
  - Recreational facilities
  - Landscaping
- Process buildings:
  - (List as required) Include in each as required substructure, superstructures, platforms, supports, stairways, ladders, access ways, cranes, monorails, hoists, elevators
- Auxiliary buildings:
  - Administration and office
  - Medical or dispensary
  - Cafeteria
  - Garage
  - Product warehouse(s)
  - Parts or stores warehouse
  - Maintenance shops—electric, piping, sheet metal, machine, welding, carpenters, instrument
  - Guard and safety
  - Hose houses
  - Change houses
  - Smoking stations (in hazardous plants)
  - Personnel building
  - Shipping office and platforms
  - Research laboratory
  - Control laboratories
- Building services:
  - Plumbing
  - Heating
  - Ventilation
  - Dust collection
  - Air conditioning
  - Sprinkler systems
  - Elevators, escalators
  - Building lighting
  - Telephones
  - Fire alarm
  - Paging
  - Intercommunication systems
  - Painting
- Process equipment:
  - (List carefully from checked flow sheets)
- Non-process equipment:
  - Office furniture and equipment
  - Cafeteria equipment
  - Safety and medical equipment
  - Shop equipment
  - Automotive heavy maintenance and yard material-handling equipment
  - Laboratory equipment
  - Lockers and locker-room benches
  - Garage equipment
  - Shelves, bins, pallets, hand trucks
  - Housekeeping equipment
  - Fire extinguishers, hoses, fire engines
- Process appurtenances:
  - Piping—carbon steel, alloy, cast iron, lead, lined, aluminum, copper, asbestos-cement, ceramic, plastic, rubber, reinforced concrete
  - Pipe hangers, fittings, valves
  - Insulation—piping, equipment
  - Instruments
  - Instrument panels
  - Electrical—panels, switches, motors, conduit, wire, fittings, feeders, grounding, instrument and control wiring
- Utilities:
  - Boiler plant
  - Incinerator
  - Ash disposal
  - Boiler feed-water treatment
  - Electric generation
  - Electric substations
  - Refrigeration plant
  - Air plant
  - Wells
  - River intake
  - Primary water treatment—filtration, coagulation, aeration
  - Secondary water treatment—deionization, demineralization, pH and hardness control
  - Cooling towers
  - Water storage
  - Effluent outfall
  - Process-waste sewers
  - Process-waste pumping stations
- Utilities: *(Continued)*
  - Sanitary-waste sewers
  - Sanitary-waste pumping stations
  - Impounders, collection basins
  - Waste treatment
  - Storm sewers
- Yard distribution and facilities (outside battery limits):
  - Process pipe lines—steam, condensate, water, gas, fuel oil, air, fire, instrument, and electric lines
  - Raw-material and finished-product handling equipment—elevators, hoists, conveyors, airveyors, cranes
  - Raw-material and finished-product storage — tanks, spheres, drums, bins, silos
  - Fuel receiving, blending, and storage
  - Product loading stations
  - Track and truck scales
- Miscellaneous:
  - Demolition and alteration work
  - Catalysts
  - Chemicals (initial charge only)
  - Spare parts and non-installed equipment spares
  - Surplus equipment, supplies and equipment allowances
  - Equipment rentals (for construction)
  - Premium time (for construction)
  - Inflation cost allowance
  - Freight charges
  - Taxes and insurance
  - Duties
  - Allowance for modifications and extra construction work during startup
- Engineering costs:
  - Administrative
  - Process, project, and general engineering
  - Drafting
  - Cost engineering
  - Procurement, expediting, and inspection
  - Travel and living expense
  - Reproductions
  - Communications
  - Scale model
  - Outside architect and engineering fees
- Construction expense:
  - Construction, operation, and maintenance of temporary sheds, offices, roads, parking lots, railroads, electrical, piping, communication, and fencing
  - Construction tools and equipment
  - Warehouse personnel and expense
  - Construction supervision
  - Accounting and timekeeping
  - Purchasing, expediting, and traffic
  - Safety and medical
  - Guards and watchmen
  - Travel and transportation allowance for craft labor
  - Fringe benefits
  - Housekeeping
  - Weather protection
  - Permits, special licenses, field tests
  - Rental of off-site space
  - Contractor's home office expense and fees
  - Taxes and insurance, interest

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* From Perry's Chemical Engineer's Handbook, McGraw Hill Book Company, New York, 4th Edition, pg 26-16 (1963).

APPENDIX 7.2

COSTS OF SPECIFIC FABRIC FILTER APPLICATIONS

Table 7.2a User Survey Cost Data.

This data was collected during a GCA survey of about fifty fabric filter installations in a wide variety of applications, as indicated. Additional data relating to the operation of these filter systems may be found in Chapter 8 of Volume I.

Table 7.2b Literature Survey Cost Data.

This data was extracted from many direct literature references to specific fabric filter applications. Because in most cases the literature was not specific as to what cost items were included, the reader is referred to the data sources.

Table 7.2c Typical Costs of Basic and Control Equipment Installed in Los Angeles County.

This Table is taken directly from the literature. Baghouse costs as listed are believed to represent the installed cost of the complete system including fan, ducting, etc.

TABLE 7.2a USER SURVEY COST DATA

Code No.	Dust	Process	Total Cost Instlln., 1969 Basis K$	Size ft^2	Cost, \$/ft^2	Size KCFM	Cost, \$/CFM	Air/Cloth Ratio	Annual Maint. (Cloth and All Labor)		Total Annual Use, Hours	T≥200°F	Fabric Life	Fabric Purch.		Replacement Labor, % of Annual Maintenance
									$	\$/CFM				\$/Bag	\$/yr	
1.1	Fly Ash	Oil Comb.	2190	147,500	14.9	820	2.7	6.	57,500	.070	8000	yes	2 yr	50.	30,000	(22)
1.2	Fly Ash	Coal Comb.		3,400		10		3.				yes				
1.3	Ash	Mun. Incin.		75		0.3		4.5				yes	10.5 mo	20		
1.4	Ash	Mun. Incin.	29	5,520	5.25	13.6	2.14	2.5			1100	yes	>2 yr			
2.1	Flour	Milling	19.8	976	20.3	8.4	2.4	8.6	650	.078	8000	No	1.5 yr	(50)	(500)	6
4.1	Dolomite	Kiln	11.5	4,590	2.5	3.3	3.5	(0.7)	1,200	.36	8000	No	1 yr	2.80	907.	20
4.2	Hypochlorite	Transport	9.4	3,020	3.11	10	0.94	3.3	4,450	.445	8000	No	7 mo	6.05	3350	9
4.3	Aluminum Hydrate	Transport	5.15	58	89	0.1	51.	1.9	1,000	10.	1100	No	3 mo	25.		(100)
5.1	Carbon Black	Mfgr.		33,175		42.5		1.6	22,100	.52	8000	Yes	1 yr	9.65	20,000	9.5
5.2	Carbon Black	Mfgr.		15,900		17.9		1.1	5,850	.33	8000	Yes	2 yr			(32)
5.3	Resin, Fiber	Transport		2,190		4		2.7	1,120	.28	8000	No	1 yr	(2.80)	864	5.5
5.4	PVA	Transport	20	1,340	15.	14	1.43	10.4	3,800	.27	8000	No	4 mo	40.	3000	11
7.1	Cement Clinker	Cooler	1440	102,000	14.	275	5.2	2.5			8000	Yes				
7.2	Cement	Mill	20.4	5,440	3.75	10	2.0	1.8	3,100	.31	8000	Yes	1 yr		1700	13
7.3	Cement	Bagging	10.8	3,370	3.2	8.3	1.3	2.5	1.500	.18	1350	No	9 mo		(500)	33
7.4	Cement	Kiln		194,400		300		1.5			8000	Yes	1 yr			
7.5	Cement	Transport		1,500		1.8			275	.13	570	No	3 yr		60	36
7.6	Lime	Kiln	1140	65,800	17.3	140	8.1	2.3	46.200	.33	8000	Yes	1.2 yr		36,300	10
7.7	$CaSO_4$	Dryer		800		6		7.5	200	.033	5700	Yes	2.5 yr			
7.8	Wallboard	Trim Saw		2,040		7		3.4	1,300	.185	5700	No	3 yr	6.	(75)	2
7.9	Stone	Crushing		2,000		(6)			(1,200)	(.20)	1900	No	4 yr			
7.10	Abrasive	Transport						2.5			6000	No	1 yr			
7.11	Raw Materials	Glass Mfgr.		72		0.17		2.3	(50)	.29	8000	No	4 mo			
7.12		Bagging	5.3	390	13.5	0.75	7.0	1.9			8000	No				
8.1	Fe, Zn Oxides	El. Fnce. Shop	2530	290,000	8.7	645	3.9	2.2	142,800	.078	8000	No	5 yr	25	14,250	(5)
8.2	Fe, Zn Oxides	Elec. Furnace	512	59,600	8.5	80	6.4	1.3	(7,900)$^+$	(.10)$^+$	8000	Yes	2.5 yr	(25)	(7,900)	
8.3	Fe_2O_3........	Elec. Furnace	176	19,600	9.0	46	3.8	3.4	(5,000)$^+$	(.11)$^+$	200	Yes	3 yr	35	3,300	33
8.4	Fe_2O_3........	Elec. Furnace	(20.4)	13,000	(1.57)	(32)	(.64)	2.3	1,370	.043	8000	Yes	3 yr	(3.)	720	18
8.5	Fe_2O_3........	Elec. Furnace	147	44,200	3.3	115	1.28	3	9,250	.08	2850	No	2.5 yr	5.	4,500	14
8.6	Fe_2O_3........	Elec. Furnace	233	42,000	5.5	60	3.9	1.4	9,300	.16	8000	Yes	>1.5yr	30		
8.7	Fe_2O_3........	Cupola		2,000		25		12.5				Yes				
8.8	Fe_2O_3.........	Cupola	880	63,600	13.8	120	7.3	2.1	135,000	1.125	4300	Yes	4 mos	10	43,800	28
8.9	Kish	Pouring	412	40,000	10.3	100	4.1	2.5			800	No	>8mo			
8.10	Fe, Coke,....	Sinter Line	235	98,500	2.4	241	1.0	2.4	(18,000)$^+$	(.075)$^+$	8000	Yes	2 yr	31	18,000	
8.11	Sand, FeO	Casting Clean.	35.2	2,390	14.7	12	2.9	5.0	3,650	.304	2300	No	1.6yr	13.50	650	35
8.12	Fe, FeO	Grinding							1,225		5200	No	13 yr		275	12
8.13	Atmos.	Motor Room Vent.		4,640		48		10.5			8000	Yes	>9yr			
9.1	ZnO	Brass Smelting	134	6,400	20.9	3.6	37.	[illegible]	4,400	1.23	8000	Yes	<1yr	2.80	1,900	23
9.2	Be. BeO	Sinter, Machine		2,080		40		20				Yes	2 yr			
9.3	Pb, PbO.....	Smelt.	291	25,600	11.4	25	11.6	1	4,900	.20	8000	Yes	1.75yr	13.70	2,500	29
9.4	ZnO, PbCl	Blast Furnace	119	153,600	.78	190	.63	1.2	210,000	1.11	8000	Yes	8 mo	27	105,000	14
9.5	Misc. Oxides	Cu Refining	910	116,000	7.8	150	6.1	1.3	80,400	.535	5000	Yes	3.5 yr	27	22,500	40
10.1	Filler, Fiber	Plastics Molding		1,660		10		6	(4,300)	.43	3800	No	1 mo	1.0	(2,760)	30

Table 7.2b

LITERATURE SURVEY COST DATA (1969 BASIS)

Ref.*	Particulate Source	Gas Flow (KCFM)	Stated System Instlln. Cost ($/CFM)	Est Total Instlln. Cost ($/CFM)	Annual O & M^x ($ per CFM-yr)	Air Power ($ per CFM-yr)	Fabric Purch.& Labor ($/set)	Fabric Life (yr.)
5	Elec. Steel Furnace	60	1.03^a	2.43	----	.25	1380	5.
5	Elec. Steel Furnace	110	1.04^a	2.44	----	.22	2190	5.
5	Elec. Steel Furnace	25	2.20	2.20	----	.24	2120	1.5
6	Oil-fired Boiler	820	4.60	4.60	.92	.085	125K	1
7	Lime Kiln	100	1.80	1.80	.20	----	----	2
8	Steel Blast Furnace	110	2.60	2.60	1.40	----	(95K)	1^+
9	Uranium Plant	93	1.46	1.46	.39	----	(4500)	3.5
10	Cement Kiln	300	3.90	3.90	----	----	----	----
11	Cement Kiln	140	1.37^b	2.37	.36	.14	----	3
12	Cement Kiln	400	1.03	1.03	----	----	----	----
12	Elec. Steel Furnace	62	1.29	1.29	----	----	----	----
13	Incinerator	140	3.09	3.09	.37	.30		1^+
13	Incinerator	64	3.81	3.81	.72	.53		1^+
14	Iron Cupola	55	4.50	4.50	.45	----	----	----
15	L.D. Steel Proc.	60	4.74	4.75	----	----	(7000)	3
16	Phosphate Roaster	71	1.70^b	2.70	.15	----	----	5
17	Elec. Steel Furnace	130	1.80	1.80	.27	.115	16.5K	3.5
17	Open Hearth Fnce	50	5.10	5.10	.52	.25	(5600)	3
18	Heavy Chem. Ind'y	60	1.66	1.66	.30	----	----	----
19	Lead Blast Fnce	262	5.25	5.25	.23	----	----	1.5
19	Lead Slag Fuming	193	5.80	5.80	.31	----	----	1.5
20	Elec. Steel Fnce.	107	2.18	2.18	----	----	21K$^+$	----
21	Asphalt Plant	40	7.50	7.50	----	----	----	----
22	Cement Kiln	146	.85^c	1.35	.19	.13	5.7K$^+$	----
22	Elec. Steel Fnce.	90	2.64^c	2.94	.41	.25	11.7K$^+$	----
23	Iron Cupola	13	3.43	3.43	----	----	----	----
23	Iron Cupola	16.9	1.78	1.78	----	----	----	----
24	Elec. Steel Fnce.	70.4	3.27	3.27	1.15	----	----	----
24	Elec. Steel (Shop)	110.	1.81	1.81	.40	----	----	----
25	Sinter Windbox	105	----	2.84	.44	----	----	----
25	Sinter Windbox	630	----	2.25	.26	----	----	----
25	Sinter Handling	48	----	5.20	.77	----	----	----
25	Sinter Handling	250	----	2.64	.38	----	----	----
25	Basic Oxygen Fnce.	288	----	5.57	.42	----	----	----
25	Basic Oxygen Fnce.	600	----	4.00	.39	----	----	-----
25	Basic Oxygen Fnce.	892	----	3.84	.37	----	----	----
25	Open Hearth Fnce.	45	----	3.55	.79	----	----	----

(continued)

Table 7.2b (contd)

Ref.[*]	Particulate Source	Gas Flow (KCFM)	Stated System Instlln Cost ($/CFM)	Est Total Instlln Cost ($/CFM)	Annual O&M[x] ($ per CFM-yr)	Air Power ($ per CFM-yr)	Fabric Purch.& Labor ($/set)	Fabric Life (yr.)
25	Open Hearth Furnace	135	----	3.21	.54	----	----	----
25	Open Hearth Furnace	350	----	3.00	.42	----	----	----
25	Elec. Steel Fnce.	60	----	3.92	.65	----	----	----
25	Elec. Steel Fnce.	230	----	3.59	.47	----	----	----
25	Elec. Steel Fnce.	350	----	3.48	.43	----	----	----
25	Elec. Steel (Shop)	125	----	3.70	.56	----	----	----
25	Elec. Steel (Shop)	750	----	2.83	.32	----	----	----
M**	Coal-fired Boiler	3100	----	2.47	----	----	----	----
M**	Open Hearth Fnce.	50	4.25	4.25	----	----	----	----
M**	Elec. Steel Fnce.	325	0.57	0.57	----	----	----	----

* For references, see Chapter 7, Volume 1.

** Miscellaneous sources of data, private communications, etc.

x Total annual operating and maintenance costs as stated are assumed to include electric power, labor, and fabric. 50% of fabric purchase costs are excluded where possible, as tax credit; labor includes 100% of wages as overhead.

a Stated costs apparently exclude duct costs and labor.

b Stated costs apparently exclude duct costs.

c Stated costs apparently exclude labor costs.

All other costs apparently include fan, ducting, and labor.

Table 7.2c TYPICAL COSTS* OF BASIC AND CONTROL EQUIPMENT INSTALLED IN LOS ANGELES COUNTY

SOURCE	SIZE OF EQUIPMENT	COST OF BASIC EQUIPMENT (dollars)	TYPE OF CONTROL EQUIPMENT	COST OF CONTROL EQUIPMENT (dollars)
Airblown asphalt system	500 bbls/batch	10,500	Afterburner	3,000
Asphalt concrete batching plant	200,000 lbs/hr	150,000	Scrubber	10,000
Asphalt saturator	6 ft x 85 ft x 8 ft	40,000	Scrubber and electrostatic precipitator	50,000
Asphalt tile production	5,000 lbs/hr	150,000	Baghouse	5,000
Borax drying and classifying	10,000 lbs/hr	1,000,000	Baghouse and scrubber	10,000
Bulk gasoline loading rack	667,000 gals/day	88,000	Vapor control system	50,000
Carbon black plant	2,000 gals/day	5,000	Baghouse	5,000
Catalytic reforming unit	2,400 bbls/day	265,000	Flare and sour water oxidizer	6,000
Ceramic tile production	8,000 lbs/hr	200,000	Scrubber	10,000
Chip dryer, aluminum	2,500 lbs/hr	3,000	Afterburner	3,000
Chrome plating	4 ft x 3 ft x 5 ft	2,000	Scrubber	800
Coffee roaster	3 tons/hr	35,000	Cyclone and afterburner	8,000
Concrete batching plant	900,000 lbs/hr	125,000	Baghouse	10,000
Core oven	8 ft x 8 ft x 12 ft	4,000	Afterburner	1,500
Crucible furnace, yellow brass	4 furnaces @ 850 lbs each/heat	2,500 (each)	Baghouse	17,000
Crude oil distillation unit	37,000 bbls/hr	3,060,300	Vapor control system	10,000
Cupola, gray iron	48 inch ID	40,000	Baghouse and quench tank	67,000
	27 inch ID	75,000	Baghouse and quench tank	32,000
Debonder	500 brake shoes /hr	1,800	Afterburner	300
Deep fat fryer, food	1000 lbs/hr	1,000	Afterburner	1,500
Delayed coker unit	9300 bbls/day	4,000,000	Scrubber (serving 3 cokers)	385,000
Drum reclamation incinerator	60 bbls/hr	10,000	Afterburner	2,000
	200 bbls/hr	75,000	Afterburner	5,000
Electric arc furnace, steel	18 tons/heat	75,000	Baghouse	46,000
Electric induction furnace, brass	2000 lbs/hr	75,000	Baghouse	2,700
Enamel frit drying	1500 lbs/hr	25,000	Baghouse	3,000
Fiberboard production	32,000 lbs/hr	10,000	Electrostatic precipitator	15,000
Fire retardant manufacturing	1000 lbs/hr	25,000	Baghouse	2,000
Fish meal system	8-20 tons/hr	100,000	Scrubber	50,000
Fixed roof storage tank for gasoline	80,000 bbls	50,000	New floating roof tank	132,000
Flue-fed incinerator	Most sizes	4,000-7,000	Afterburner	2,000
Fluid catalytic cracking unit	40,000 bbls/day	7,460,000	Electrostatic precipitator	1,040,000
			CO boiler	1,770,000
			Cyclones	165,000
			Blowdown systems, vapor manifold and flare	383,000
	7400 bbls/day	1,747,500	Electrostatic precipitator, vapor manifold and flare	131,000
Galvanizing kettle	4 ft x 30 ft x 4 ft	25,000	Baghouse	3,000
Grit blasting machine	6 cu ft	9,300	Baghouse	1,700
Insecticide manufacturing	1000 lbs/hr	10,000	Baghouse	3,000
Insulation production, including cupola, blow chamber and curing oven	5000 lbs/hr	13,000	Baghouse, scrubber and afterburner	30,000
Liquid hydrogen manufacturing	32 tons/day	8,382,000	Flare	17,700
Lithographing oven	240 ft/min	78,000	Afterburner	16,000

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*Cost indicated relates to time of equipment installation.

Table 7.2c (Continued)

SOURCE	SIZE OF EQUIPMENT	COST OF BASIC EQUIPMENT (dollars)	TYPE OF CONTROL EQUIPMENT	COST OF CONTROL EQUIPMENT (dollars)
Multiple-chamber incinerator industrial and commercial	50 lbs/hr	800	-	-
	500 lbs/hr	6.500	-	-
	6000 lbs/hr	75.000	-	-
Multiple-chamber incinerator, pathological	50 lbs/hr	1.000	-	-
	200 lbs/hr	4 500	-	-
Multiple-chamber incinerator, wire reclamation	100 lbs/hr	1 200	-	-
	1000 lbs/hr	15 000	-	-
Multiple-chamber incinerator, with continuous feed bin	250 lbs/hr	5 000	-	-
	3000 lbs/hr	45.000	-	-
Natural gas plant	20,000,000 cu ft/day	220.000	Vapor manifold and flare	5,000
Oil-water separator	300,000 bbls/day	170.000	Floating roof	80,000
	350 bbls/day	17 000	Cover	700
	3500 bbls/day	32.000	Floating roof	8,000
Open hearth furnace, steel	60 tons/heat	200.000	Electrostatic precipitator	150,000
Phosphate fertilizer production	2000 lbs/hr	10.000	Baghouse	5,000
Phthalic anhydride manufacturing	25,000,000 lbs/yr	1 200.000	Afterburner and baghouse	195,000
Pipe coating, including spinning, wrapping and dipping	4-10 lengths/hr	23.500	Scrubbers	32,000
Pneumatic conveyors (minerals)	200 to 5000 lbs/hr	2 000	Cyclone and baghouse	2,000
Pot furnace, type metal	16,000 lbs	9.000	Afterburner	3,000
Rendered grease processing	6 tons/day	10.000	Contact condenser and afterburner	2,500
Rendering cooker and drier, (batch)	4 tons/batch	10 000	Surface condenser and afterburner	15,000
Rendering cooker system, (continuous)	15 tons/hr	100.000	Surface condenser and afterburner	25,000
Rock crushing and sizing	300,000 lbs/hr	75.000	Scrubber	2,000
Rotogravure press	5-color, 44 inch web	340.000	Activated carbon filter	40,000
Rubber 'Banbury' mixer	1000 lbs/hr	25.000	Baghouse	3,000
Sandblast room	8 ft x 12 ft x 8 ft	1.600	Baghouse	3,000
Sewage treatment digestion	900,000 gals/day	800,000	Water seals and flares	7,000
Sewage treatment headworks	250,000,000 gals/day	550,000	Covers	20,000
Sewage water reclamation	17,000,000 gals/day	1,500,000	Covers and aeration tanks	25,000
Sewer pipe manufacturing	20,000 lbs/hr	1,000,000	Baghouse	10,000
Ship bulk loading	2500 tons/hr	500,000	Baghouse	168,000
Smoke generator and smokehouse	11 ft x 12 ft x 11 ft	18,000	Precipitator, scrubber and afterburner	42,000
Sulfuric acid plant	250 tons/day	1,900,000	Electrostatic precipitator	150,000
Sulfur recovery plant	Two parallel units, 65 tons/day, each	1,400,000	Incinerator	30,000
	10 tons/day	265,000	Incinerator	5,000
	2840 lbs/day	30,000	Incinerator	1,000
	8000 lbs/day	60,000	Incinerator	1,000
Sweat furnace, aluminum	3000 lbs/hr	3,500	Afterburner and baghouse	3,500
Synthetic rubber manufacturing	30,000 tons/yr	1,800,000	Vapor manifold and flare	250,000
Synthetic solvent dry cleaner	60 lbs/batch	14,000	Activated carbon filter	3,000
Varnish cookers (2)	250 gallons each	4,000	Afterburner	5,500
Wallboard production	60,000 lbs/hr	1,500,000	Baghouse	100,000

APPENDIX 8.1

TROUBLESHOOTING CHECKLISTS

The following extractions of operating and maintenance suggestions from the brochures of three fabric filter manufacturers are typical of those in current manufacturer's manuals. While each brochure was prepared for a specific type of equipment and was not intended to be a general guide, the comments have some general applicability.

(1) TROUBLESHOOTING CHECKLIST FOR FABRIC FILTERS*

"Condition: High differential pressure (Note: Most installations are designed for differential pressure of 3 to 4 in. A differential pressure of 1 in. to 6 in. can be considered normal).

1. Improper compressed air supply (80 to 100 psig is required. More effective cleaning is possible with pressures up to 110 psig).

2. Improper timer operation. Make sure all valves are being activated. Check for sticking timer relay.

3. Improper solenoid valve operation. A leaking diaphragm will reduce cleaning energy by slowing or preventing valve opening.

4. Leaky airlock or dust discharge valve can overload collector by preventing dust discharge.

5. Moisture blinded bags. Recovery is often possible by running the cleaning mechanism without moving air through the collector from one to 30 hours.

6. Considerable dust in the clean air plenum (from a previously leaky bag, etc) can reduce cleaning effectiveness by impregnating the bags in the reverse direction.

7. Static electricity can cause a high differential pressure. Increase humidity if possible.

8. Make sure blow tubes are installed correctly (field assembly units).

9. Collector overloaded by too much air. Check fan speed. Check damper adjustment and system design.

"Condition: Seepage - Visible discharge
Points to check and remedy:

1. Improperly installed bags.
2. Loose bag clamps.
3. Torn bags or holes in bags.
4. Improper sealing of tube sheet joints (field assembled units).
5. Missing or loose venturi rivets.

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* Primarily for pulse cleaned equipment; from Mikro-pulsaire Instruction Manual, Pulverizing Machinery Corp.

"Condition: Insufficient suction on exhaust hood or system
Points to check and remedy:

1. Fan direction of rotation incorrect. Fan will pump air inefficiently if wrong direction.

2. Check for high differential pressure (see above).

3. Slippage on fan belts?

4. Leaking duct work? Access doors? Explosion doors? Discharge valve on air lock?

5. Clogged duct, or closed gate, or damper.

6. Duct size or run other than original design.

7. Poor system design?

"Condition: Unable to maintain compressed air pressure
Points to check and remedy:

1. Dirty solenoid valve sticking open Clean and check pilot plunger.

2. Short circuit in wiring keeping one or more valves open.

3. Sticking timer relay, or pulse longer than 0.15 seconds.

4. Faulty or too small a compressor, and/or pipe leaks.

5. Solenoid valves require a minimum of 5 psig to close. A long compressed air run after the shut-off valve can prevent the required 5 psig from developing. Solution to this would be provision of reservoir and shut-off valve near the collector.

"Condition: Filter cylinder problems (blinding, poor life, etc.)
Points to check and remedy:

1. Check operating temperature (e.g. 180 deg. for wool).

2. Check operating humidity, free moisture, etc. (relative humidity is too low if static electricity occurs).

3. Check for shrinkage, free moisture, etc.

4. Review physical and chemical characteristics of material and gas stream.

5. Check for hopper bridging. Material buildup into the bag area can overstress elements.

6. Incorrect bag retainer installation can cause bag wear by allowing friction between adjacent elements or between outside elements and housing. Make sure tubes are installed vertically. "

(2) "THE CARE OF A DUST CONTROL SYSTEM*

"Dust control systems have, in the past, been subject to an unusual amount of neglect and disregard after installation. Possibly most of this is due to the fact that the installation in itself is non-productive; its chief function in most cases being the abatement of a nuisance. Many times, also, the responsibility of upkeep has been shouldered onto an already over-burdened millwright who has had to neglect the dust control installation in order to keep actual production machinery in operation. Many times, upon being questioned about the performance of such equipment, the superintendent will say "It's working fine, we haven't looked into it for several years." This is obviously an altogether wrong attitude to take.

"The responsibility for the operation and maintenance of dust control equipment should be placed in the hands of a competent mechanic, who should make observations, as pointed out below, either monthly or semi-monthly. He should make dated reports in duplicate, with one copy for the plant manager, the other for his own records. The neglect of a seemingly unimportant repair may cause excessive damage to the installation and require a lengthy shut down.

"A test of collecting efficiency should be made semi-yearly, at least, by a competent individual using recognized technique in dust counting. Possibly your insurance connection includes this service. U.S. Public Health Bulletin No. 217 entitled "The Determination and Control of Industrial Dust" explains fully the various methods used. It also contains other pertinent information. This bulletin may be obtained from the Superintendent of Documents, The United States Government Printing Office, Washington, D.C., for 15 cents in cash.

"Daily Attention ("Dustubes"): By watching the permanent manometer on the dust collector, the proper time for operating the shaking device can be determined. See your repair and instruction book for further details. Hoppers should be emptied daily. Exhaust fans must not be in operation while cleaning.

"CHECKING POINTS

1. Inspect all hoods and piping for wear by abrasion. This will naturally occur at the portion of the hood where dust is thrown by the force of the operation which creates it. If the interior of the hood is visible, the path of the material can be noted from the appearance of the metal. Backs of elbows and bends in pipe lines and main lines, opposite the entrance of branch pipes will receive the greatest wear.

Hoods should also be checked for any structural damage caused by impact with the product being processed. Hood doors should fit tightly. Leaks in pipe lines can be detected by noting breaks in soldered joints, etc. Such leaks can often be located approximately from the hissing sound of inrushing air: Soap suds applied to doubtful points with a brush will definitely locate the leak. By tapping on the bottom of the pipe with a light hammer or other metal object, dust accumulation can be detected by the dead thud, as compared with the hollow sound of a clean pipe. Make sure that the cleanout slides fit tightly. Check the blast gates for proper setting and wear. Also see that the pipe supporting members are in shape.

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* From "Manual of Engineering Information", American Wheelabrator and Equipment Corporation, Catalog #72-A.

2. Check the pipe connections to the collector housing and the seams of the housing proper for leaks, as explained above. Be sure that the hopper valve works freely and that it seats tightly.

3. Enter the clean air side of the collector ("Dustubes") with a flashlight or extension light and check for dust leaks made evident by the excessive accumulation of dust in certain spots. Replace worn tubes immediately. Check shaking device for wear and lubrication. At bi-monthly intervals, enter the dusty air side of the collector, and note the condition of baffles, etc., as well as the condition of the cloth from this side.

4. Check the condition of fan bearings and lubrication. If unusual vibration is noted, examine the rotor for wear or accumulation of dust on the blades. Also be sure that the rotor is tight on the shaft, and that it has not slipped to one side of the housing. A tight inspection door on the housing side will facilitate inspection. See that the joints in the scroll of the fan are bolted tightly, and do not show excessive wear.

5. Check the suction and volume readings with the pilot tube and manometer. Compare these with the original readings at time of installation. Be sure that readings are taken under duplicate operating conditions as nearly as possible. Two sets of readings should be taken, one just after the operation of the shaking device, the other just before the next shaker operation."

(3) OPERATING GUIDE

OPERATION*

"As a final check before starting equipment, review installation instructions and drawing which give operating conditions for which equipment is intended. Should conditions be other than stated on drawing, it is recommended you contact the Flex-Kleen Corporation or its nearest representative to determine whether equipment will function properly under the existing conditions. If a manometer is furnished, it should be connected with one end above and one end below bag plate, so it will show the pressure drop across bag filter. After collector has operated two hours on a heavy dust load or eight hours the "VALVE ON TIME" should be readjusted. This is done with the inspection door open so the flexing action can be observed while collector is handling air. "VALVE ON TIME" will have to be turned very slightly to obtain maximum shock with dust loaded bags. Close inspection door and after thirty minutes operation check pressure drop. If within four to six inches of water, the "VALVE OFF TIME" cycle is correct. A pressure drop of less than four inches of water indicates the "VALVE OFF TIME" cycle can be increased, thus saving on compressed air. Should pressure drop be greater than six inches, it will be necessary to decrease "VALVE OFF TIME" cycle until pressure drop is within acceptable four to six inches of water range.

"MAINTENANCE

Daily visual inspection of the clean air discharge, will assure you of early warning of bag failure. A dirty discharge means a broken bag, holes in the bags, or loose bag clamps. It is recommended the filter bags be inspected after 2480 hours operation or three months continuous operation. Normal bag life varies considerably and it is recommended that records be maintained so that bag replacements can be scheduled for regular plant shutdowns rather than waiting for signs of bag failures. It has been found to be more economical to replace all bags rather than one at a time, once bags begin to show signs of wear. Should timer require repairs which are too difficult for available personnel, a reconditioned timer may be ordered from the Flex-Kleen Corporation. The charges for the reconditioned timer will be based on the cost of repairing and reconditioning the returned timer. When ordering any parts, bags or timers, be sure to give serial number and model number of collector.

"IN CASE OF TROUBLE --

Things to Check and Solution

1. Dirty Discharge
   a. Filter bags, check for holes and replace worn bags.
   b. Bag clamps. Make certain clamps are completely tight.
   c. Improperly installed bags. Review bag installation instructions.

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* From Flex-Kleen Corporation Bulletin No. 1010. Primarily for pulse cleaned equipment.

2. High Pressure Drop

   a. Timer. Check cover lights to make certain it is operating and at proper frequency.
   b. Solenoid valves not opening. Look for loose wires, dirt clogged in valves.

   c. Wet filter bags. If compressed air has water in it, use after cooler or water trap on line. Check dew point of dust laden air and insulate collector if necessary.
   d. Dust discharge valve.
   e. Compressed air supply. 90-100 psig for optimum results. Use air receiver or larger line if pressure insufficient.

3. Insufficient Air Capacity or Suction

   a. Check point 2 above.
   b. Blower speed.
   c. Partially closed blast gate.
   d. Leaking pipe and elbows.
   e. Plugged pipes.
   f. Inoperative discharge valve.

4. Poor Bag Life.

   a. Operating temperature.
   b. Filter ratio.
   c. pH of dust.
   d. Dew point of air, if high it may be necessary to insulate collector. "

APPENDIX 8.2

FABRIC AND SYSTEM OPERATIONAL PROBLEMS

Explanation of Column Headings:

Code No.: Fabric Filter Installation Survey Code
Δp_{max} : Maximum Pressure Drop Observed across the Fabric, (inches of water)
Particle Abrasiveness: Very Abrasive, Abrasive, Moderately Abrasive, Not Abrasive
Problem Category: See Table 8.1 of Volume 1 for Explanation.

TABLE 8.2 FABRIC AND SYSTEM OPERATIONAL PROBLEMS

Code No.	Dust	Process	Particle Size, µ	Fabric Area, ft^2	A/C Ratio	Δp_{max}	Temp °F	Fabric Mat'l.	Cleaning Method	Particle Abrasiveness	Fabric Life	Total Annual Maint. $/CFM	Problem Category				
													1	2	3	4	5
1.1	Fly ash	Oil Comb.	<1µ	147,500	6	7	258	Glass	R.Flex	(VA)	2 yr	.070	b,c,e,i				
1.2	Fly ash	Coal Comb.	(75)	3,400	3	3	(300)	Glass	R Flow	VA							
1.3	Ash	Mun. Incin.	(10)	75	4.5	5	450	Glass	Pulsed R.Flow	A	10.5mo		i,g,h				
1.4	Ash	Mun. Incin.	~ 3	5,520	2.5	4.1	480	Glass	R. Flex	A	>2yr						
2.1	Flour	Milling	1-30	976	8.6	5.5	110	Wool F	R.Jet	N	1. yr	.078	a,d			d,e	
4.1	Dolomite	Kiln	40	4,590	(0.7)	3.5	150	Dacron^R	R.Flex	A	1 yr	.36	a,b,f	a	a,b		a
4.2	Hypochlorite	Transport	~50	3,020	3.3	3	Amb	Dynel^R	Shake	M	7 mo	.445	b,d		a	e	
4.3	Aluminum Hydrate	Transport	100	58	1.9	2	Amb	Dacron^R F	Pulse Jet	VA	3 mo	10.	d		c		a
5.1	Carbon Black	Mfgr.	<1µ	33,175	1.6	8	425	Glass	R.Flow	M	1 yr	.52			c	a,b	
5.2	Carbon Black	Mfgr.	<1µ	15,900	1.1	7	375	Glass	R.Flow & Sh.	M	2 yr	.33	a,c,h	a	c	a	
5.3	Resin, Fiber	Transport	1-100	2,190	2.7	(6)	Amb	Cotton	Shake	M	1 yr	.28	a,d,e,f,h		e	b	
5.4	PVA	Transport	3	1,340	10.4	3	Amb	Wool F	Pulsed R.Flow	M	4 mo	.27	d,g	b	c		
7.1	Cement Clinker	Cooler	50	102,000	2.5	5.5	450	Glass	R. Flex	VA							
7.2	Cement	Mill	20	5,440	1.8	3	325	Cotton	Shake	VA	1 yr	.31	a,h		d	a,c,d	
7.3	Cement	Bagging	10	3,370	2.5	3	<100	Cotton	R. Flow	VA	9 mo	.18	b,e,f		a	e	
7.4	Cement	Kiln	15	194,400	1.5	5	525	Glass	R. Flex	VA	1 yr		b				
7.5	Cement	Transport	10	1,500			Amb	Cotton	R. Flow	VA	3 yr	.13	d				a
7.6	Lime	Kiln	(15)	65,800	2.3	5	500	Glass	R.Flow&For.Pulse	VA	1.2 yr	.33	a,b		c		a
7.7	CaSO$_4$	Dryer	5	800	7.5		200	Dacron^R	Pulse Jet	A	2.5 yr	.033	b	b			
7.8	Wallboard	Trim Saw	>10	2,040	3.4		140	Cotton	Shake	A	3 yr	.185	d	b		c,e	
7.9	Stone	Crushing	100	2,000			Amb	Cotton	Shake	VA	4 yr	(.20)				e	
7.10	Abrasive	Transport	<10-100		2.5	3	Amb	Cotton	Shake	VA	1 yr		a,d,f		e	c	b
7.11	Raw Materials	Glass Mfgr.	<200	72	2.3	3	Amb	Cotton	Shake	VA	4 mo	.29		b			
7.12		Bagging		390	1.9	6	Amb	Cotton	Shake	A							
8.1	Fe, Zn Oxides	El. Fnce. Shop	(10)	290,000	2.2	6	195	Glass	R. Flex	VA	4 yr	.078				c	b
8.2	Fe, Zn Oxides	Elec. Fnce.	~10	59,600	1.3		400	Glass	R. Flex	VA	2.5yr	(.10)$^+$	a			a,c	
8.3	Fe$_2$O$_3$...	Elec. Fnce.	<1µ	19,600	3.4	5	215	Dacron^R/Orlon^R	Shake&R.Flex	VA	3 yr	(.11)$^+$	c,e			c	
8.4	Fe$_2$O$_3$...	Elec. Fnce.	<1µ	13,000	2.3		330	Orlon^R	Shake	VA	3 yr	.043	b,c,e,f				
8.5	Fe$_2$O$_3$...	Elec. Fnce.	<1µ	44,200	3	2.5	110	Orlon^R	Shake	VA	2.5yr	.08	b,c,g			c,d,e	
8.6	Fe$_2$O$_3$...	Elec. Fnce.	<1µ	42,000	1.4	7	225	Dacron^R	R. Flow	VA	>1.5yr	.16					b
8.7	Fe$_2$O$_3$	Cupola	.5-50	2,000	12.5	9.3	240	Nomex^R	Pulse	VA							
8.8	Fe$_2$O$_3$	Cupola	.5-50	63,600	2.1	9	450	Glass	Shake	VA	4 mo	1.125	a,b,e,h			e	
8.9	Kish	Pouring	80	40,000	2.5	10.5	200	Dacron^R	Shake	A	>8mo				c	d	
8.10	Fe, Coke,...	Sinter Line	1-400	98,500	2.4	6.7	287	Glass	R. Flex	VA	2 yr	(.075)$^+$	b			c,e	a,b
8.11	Sand, FeO	Casting Clean.	<200	2,390	5.0	8	Amb	Cotton	R. Jet	VA	1.6yr	.30	f			d	
8.12	Fe, FeO	Grinding	~50				Amb	Cotton	Shake	VA	13. yr		d,g			e	
8.13	Atmos.	Motor Room Vent.	<1µ	4,640	10.5		80	Cotton	Shake	N	>9yr						
9.1	ZnO	Brass Smelt.	<1µ	6,400	0.6	3	600	Glass	Shake&R.Flow	A	<1yr	1.23	e,f				
9.2	Be, BeO...	Sinter,Machine	1-10	2,080	20		250	Polyprop.	R.Jet	A	2 yr		a,d				
9.3	Pb, PbO...	Smelt.	.5-10	25,600	1	3	275	Dacron^R	Shake&R.Flow	A	1.75yr	.20	d,i				
9.4	ZnO, PbCl	Blast Fnce.	<1µ	153,600	1.2	10	375	Glass	Shake	M	8 mo	1.11	a,b,d,e,i			c,e	
9.5	Misc. Oxides	Cu Refining	(50)	116,000	2.0	7	350	Nomex^R	Shake	M	3.5yr	.35	f				
10.1	Filler, Fiber	Plastics Molding	50-500	1,660	6		Amb	Cotton	Shake	VA	1 mo	.43	a,c,d,e			a,c,e	

APPENDIX 8.3

OPERATIONAL PROBLEM CATEGORY ANALYSIS

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OPERATIONAL PROBLEM CATEGORY ANALYSIS

In this appendix the operational problems reported in Section 8.3 and listed according to industrial application in Appendix 8.2 are regrouped according to type of problem. There are 23 such problem categories.

Explanation of column headings:

Survey Code: Fabric filter installation survey code

Mfgr: Fabric Filter manufacturer:

A: American Air Filter
C: Carter-Day
D: Dustex
F: Flex-Kleen
H: Hydromation
N: Norblo
P: Pangborn
S: Sly
W: Wheelabrator
Hmd: Homemade

Proc: Industrial process creating the dust or fume.

P.S.: Particle size, in microns.

Temp: N = not over 200°F; Y = Yes, over 200°F.

Dust Abrasive Rating: VA = Very abrasive; A = Abrasive; M = Moderately abrasive; N = Not abrasive.

OPERATIONAL PROBLEM CATEGORY ANALYSIS

Category	Survey Code	Mfgr.	Size of Unit Sq. ft.	cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
1a	(8) Dust-related abrasion, wear									
	4.1	N	4590	$3.3_{0.7}$		CaO	40	N	A	Dacron^{R}
	9.2	C	2080	40_{20}		BeO	1	Y	-	Poly-prp. felt
	7.10	P	----	$--_{(2.5)}$	Hdlg	Abr.	50	N	VA	Cotton
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P.Cem.	10	N	VA	Cotton
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl. Resin.	50	N	M	Cotton
	10.1	P	1660	10_{6}		Fibr. plafil.	50	N	M?	Cotton
	8.8	W	63,600	$120_{2.1}$		Cupola	10	Y	-	Glass
	7.6	D	65,800	$140_{2.3}$	Kiln	CaO		Y	A	Glass
1b	(10) Flexure wear failure									
	4.1	N	4590	$3.3_{0.7}$		CaO	40	N	A	Dacron^{R}
	7.2	N	5440	$10_{1.8}$	Mill	PC Clinker	-	Y	VA	Cotton
	8.8	W	63,600	$120_{2.1}$		Cupola	10	Y	-	Glass
	7.6	D	65,800	$140_{2.3}$	Kiln	CaO	-	Y	A	Glass

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit		Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
			Sq. ft	cfm $\times 10^{-3}$ (A/c R)						
	8.5	W	44,240	$115_{3.0}$	El Fnc	Steel Fume	1	N	N	Orlon^R
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu, PbCl,...	-	Y	N	Glass
	4.2	N	3020	$10_{3.3}$	Hdlg	Hypo-chlor.	100	N	A	Dynel^R
	7.7	F	800	$6_{7.5}$	Hdlg	Gyps.	7	Y	A	Dacron^R
	5.2	Hmd	15,900	$17.9_{1.1}$	-	Cbn Blk	$< .1$	Y	N	Glass
	2.1	C	976	$8.4_{8.6}$	Mill	Flour	15	N	N	Wool Felt
1c	(4) Seeping									
	5.2	Hmd	15,900	$17.9_{1.1}$	-	Cbn Blk	$< .1$	Y	N	Glass
	8.4	W	10,040	$32_{3.0}$	Elec Fnc	Fe_2O_3...	-	Y	N	Orlon^R
	10.1	P	1660	10_{6}		Fibr, plafil.	50	N	M?	Cotton
	8.5	W	44,240	$115_{3.0}$	Elec Fnc	Steel Fume	1	N	N	Orlon^R
1d	(14) Blinding									
	7.2	C	2080	40_{20}		BeO	1	Y	-	Polypro felt
	5.1	W	33,175	$42.5_{1.6}$	-	Cbn Blk	$< .1$	Y	N	Glass

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq. ft.	cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
	7.10	P	----	$---_{2.5}$	Hdlg	Abr.	50	N	VA	Cotton
	5.4	CD	1340	$14_{10.4}$	Hdlg	PVA	3	N	A	Wool Felt
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl resin	50	N	Mildly	Cotton
	4.3	F	58	$0.1_{1.9}$	Hdlg	Alum. Hyd.	100	N	VA	Dacron Felt
	10.1	P	1660	10_{6}		Fibr, plafil	50	N	M?	Cotton
	9.3	Hmd	25,600	25.	-	PbO, SnO...	-	Y	N	Dacron^{R}
	2.1	CD	976	$8.4_{8.6}$	Mill	Flour	15	N	N	Wool Felt
	4.2	N	3020	$10_{3.3}$	Hdlg	Hypo-chlor.	100	N	A	Dynel^{R}
	8.12	P	-	$-_{-}$	Fndry	Casting Cleaning	-	N	A?	Cotton
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu, PbCl...	-	Y	N	Glass
	7.8	P	2040	$7_{3.4}$	Sawing	Gypsum	∞	N	A	Cotton
	7.5	S	1496	$2.16_{1.82}$	Hdlg	P. Cement	-	N	A	Cotton
1e	(6) Burning, heat									
	9.1	Hmd	6400	$3.6_{0.6}$	Smelt	ZnO	-	Y	N	Glass
	8.4	W	10,040	$32_{3.0}$	Elec Fnc	Fe_2O_3	-	Y	N	Glass

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
	7.2	N	5440	$10_{1.8}$	Mill	PC Clinker	-	Y	VA	Cotton
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl. Resin.	50	N	Mildly?	Cotton
	8.1	W	63,600	$120_{2.1}$	-	Cupola	10	Y	-	Glass
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu, PbCl	-	Y	N	Glass
1f	(6) Holes, pinholes, shot holes									
	4.1	N	4590	$3.3_{0.7}$	-	CaO	40	N	A	Dacron^{R}
	9.1	Hmd	6400	$3.6_{0.6}$	Smelt	ZnO	-	Y	N	Glass
	8.11	A	2390	$12_{5.0}$	Fndry Casting	Clean, shake	-	N	A	Cotton
	8.4	W	10,040	$32_{3.0}$	Elec Fnc	Fe_2O_3	-	Y	N	Glass
	7.2	N	5440	$10_{1.8}$	Mill	PC Clinker	-	Y	VA	Cotton
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl. resin.	50	N	Mildly?	Cotton
1g	(4) Hygroscopicity									
	5.4	CD	1340	$14_{10.4}$	Hdlg	PVA	3	N	A	Wool. Felt
	8.5	W	44,240	$114_{3.0}$	Elec Fnc	Steel Fume	1	N	N	Orlon^{R}

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	cfm $\times 10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
	1.3	Exptl	75	$0.3_{4.5}$	Incin.	Ash	-	-	N	Glass
	8.12	P	---	----	Fndry Casting	Clean-ing	-	N	A?	Cotton
1h	(5) Condensation									
	5.2	Hmd	15,900	$17.9_{1.1}$	-	Cbn Blk	< .1	Y	N	Glass
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P. Cem.	10	N	VA	Cotton
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl. resin.	50	N	Mildly?	Cotton
	8.8	W	63,600	$120_{2.1}$	-	Cupola	10	Y	-	Glass
	1.3	Exptl	75	$0.3_{4.5}$	Incin.	Ash	-	-	N	Glass
1i	(e) Cake hardening									
	9.3	Hmd	25,600	25.	-	PbO, SnO...	-	Y	N	Dacron^{R}
	1.3	Exptl	75	$0.3_{4.5}$	Incin.	Ash	-	-	N	Glass
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu, PbCl	-	Y	N	Glass
2a	(2) Seams, sewing									
	4.1	N	4590	$3.3_{0.7}$	-	CaO	40	N	A	Dacron
	5.2	Hmd	15,900	$17.9_{1.1}$	-	Cbn Blk	< .1	Y	N	Glass

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	Size of Unit cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
2b	(4) Tears at top									
	7.11	S	72	$0.17_{2.3}$	Hdlg	Sands	200	N	VA	Cotton
	5.4	CD	1340	$14_{10.4}$	Hdlg	PVA	3	N	A	Wool Felt
	7.8	P	2040	$7_{3.4}$	Sawing	Gyps.	∞	N	A	Cotton
	7.7	F	800	$6_{7.5}$	Hdlg	Gyps.	7	Y	A	Dacron^R
3a	(3) Chafe									
	4.1	N	4500	$3.3_{0.7}$	-	CaO	40	N	A	Dacron^R
	7.2	N	5440	$10_{1.8}$	Mill	PC Clinker	-	Y	VA	Cotton
	4.2	N	3020	$10_{3.3}$	Hdlg	Hypo-chlor.	100	N	A	Dynel^R
3b	(1) Tensioning									
	4.1									
3c	(5) Support abrasion									
	5.1	W	33,175	$42.5_{1.6}$	-	Cbn Blk	< .1	Y	N	Glass
	4.3	F	58	$0.1_{1.9}$	Hdlg	Alum. Hyd.	100	N	VA	Dacron^R Felt
	7.6	D	65,800	$140_{2.3}$	Kiln	CaO	-	Y	A	Glass
	5.2	Hmd	15,900	$17.9_{1.1}$	-	Cbn Blk	< .1	Y	N	Glass
	5.4	CD	1340	$14_{10.4}$	Hdlg	PVA	3	N	A	Wool Felt

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
3d	(1) Carriage wear									
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P. Cem.	10	N	VA	Cotton
3e	(2) Seals around collars									
	7.10	P	-	$-_{2.5}$	Hdlg	Abr.	50	N	VA	Cotton
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl. Resin	50	N	Mildly?	Cotton
4a	(4) Difficult entry									
	5.1	W	33,175	$42.5_{1.6}$	-	Cbn Blk	< .1	Y	N	Glass
	5.2	Hmd	14,900	$17.9_{1.1}$	Elec Fnc	Fe_2O_3	-	Y	N	Orlon^R
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P. Cem.	10	N	VA	Cotton
	10.1	P	1660	$10_{1.6}$	-	Fibr Pl fil	50	N	M?	Cotton
4b	(3) Hole detection									
	5.1	W	33,175	$42.5_{1.6}$	-	Cbn Blk	< .1	Y	N	Glass
	8.4	W	10,045	$32_{3.0}$	Elec Fnc	Fe_2O_3	-	Y	N	Orlon^R
	5.3	W	2190	$4_{2.7}$	Hdlg	Pl Resin	50	N	Mildly	Cotton

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	Size of Unit cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
4c	(6) Hopper holdup									
	7.10	P	-	$-_{2.5}$	Hdlg	Abr.	50	N	VA	Cotton
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P. Cem.	10	N	VA	Cotton
	10.1	P	1660	10_{6}	-	Fibr, Pl.fil.	50	N	M?	Cotton
	8.5	W	44,240	$115_{3.0}$	Elec Fnc	Steel	1	N	N	Orlon^{R}
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu,PbCl	-	Y	N	Glass
	7.8	P	2040	$7_{3.4}$	Sawing	Byps.	∞	N	A	Cotton
4d	(4) Internal mechanism									
	8.11	A	2390	$12_{5.0}$	Fndry Cast	Clean Shake	-	N	A	Cotton
	7.3	S	3366	$8.3_{2.5}$	Hdlg	P. Cem.	10	N	VA	Cotton
	2.1	CD	976	$8.4_{8.6}$	Mill	Flour	15	N	N	Wool Felt
	8.5	W	44,240	$115_{3.0}$	Elec Fnc	Steel	1	N	N	Orlon^{R}
4e	(10) External mechanism									
	7.2	N	5440	$10_{1.8}$	Mill	P.C. Clinker	-	Y	VA	Cotton
	7.9	A	2002	$-_{-}$	Crash	Stone	100	N	A	Cotton
	2.1	CD	976	$8.4_{8.6}$	Mill	Flour	15	N	N	Wool Felt

OPERATIONAL PROBLEM CATEGORY ANALYSIS (Continued)

Category	Survey Code	Mfgr.	Size of Unit Sq.ft.	cfm $x10^{-3}$ (A/c R)	Proc.	Dust	P.S.	Temp	Dust Abrasive Rating	Fabric in Use
	10.1	P	1660	10_{6}	-	Fibr. Pl.fil.	50	N	M?	Cotton
	8.8	W	63,600	$120_{2.1}$	-	Cupola	10	Y	-	Glass
	8.5	W	44,240	$115_{3.0}$	Elec Fnc	Steel	1	N	N	Orlon^R
	9.4	W	153,600	$190_{1.2}$	Bl Fnc	Cu, PbCl	-	Y	N	Glass
	4.2	N	3020	$10_{3.3}$	Hldg	Hypo-chlor.	100	N	A	Dynel^R
	8.12	P	-	$-_{-}$	Fndry	Casting Ang	-	N	A?	Cotton
	7.8	P	2040	$7_{3.4}$	Sawing	Gypsum	∞	N	A	Cotton
5a	(4) Ducting abrasion									
	4.1	N	4590	$3.3_{0.7}$	-	CaO	40	N	A	Dacron^R
	4.3	F	58	$0.1_{1.9}$	Hdlg	Alum. Hyd.	100	N	VA	Dacron^R Felt
	7.6	D	65,800	$140_{2.3}$	Kiln	CaO	-	Y	A	Glass
	7.5	S	1496	$2.16_{1.82}$	Hdlg	P. Cem.	-	N	A	Cotton
5b	(3) Inlet control									
	7.10	P	-	$-_{2.5}$	Hdlg	Abr.	50	N	VA	Cotton
	8.5	W	44,240	$115_{3.0}$	Elec Fnc	Steel Fume	1	N	N	Orlon^R
	8.6	A	42,000	$60_{1.4}$	Elec Fnc	Steel Fume	1	Y	N	Dacron^R

APPENDIX 8.4

MAINTENANCE PROBLEMS ENCOUNTERED IN THE DEVELOPMENT OF NEW APPLICATIONS

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The following three accounts taken from the literature describe the kinds of problems typically encountered when pollution control equipment such as a fabric filter system is being developed for an industrial effluent for which there is little background experience.

8.4a	Iron and Steel Industry: Sinter Plant Discharge (1968)
8.4b	Combustion: Oil-fired Power Plant Boiler (1968)
8.4c	Non-ferrous Metals Industry: Copper Smelter (Pilot and Full-scale Equipment) (1960)

8.4a Sinter Plant Discharge - U.S. Steel Corporation at its Gary, Indiana works replaced an inadequate dust control system in the sinter plant. Part of the replacement equipment was a fabric filter system in the discharge area of one of three sinter strands. An induced draft fan took dust from 18 pick-up points to an upward-flow, inside-filtering, collapse-cleaned baghouse. Dust from the hoppers went through a rubber dribble to a conveyor belt, and then to a wetting system for return to process. The following is a direct quote:*

"Design and Operating Data

Volume of air:	172,000 CFM at 255 deg. F.
Suction:	12 inches of water
Pressure drop across bags:	4 inches of water
Number of hoppers in collector:	10
Bags per hopper:	88
Total number of bags:	880
Bag Size:	
Diameter:	11 1/2 inches
Length:	32 feet 2 1/4 inches
Type Bag:	Fiberglass
Estimated Life of bag:	12 mos. - actual 17 mos.
Bag Permeability:	12 to 20 CFM/Sq. Ft. of cloth
Air to cloth ratio - normal:	2.17 CFM/Sq. Ft. of cloth
Air to cloth ratio - one compartment cleaning:	2.41 CFM/Sq. Ft. of cloth
Air temperature:	175 deg. F to 300 deg. F.
Theoretical Design Efficiency:	Excess of 99.0 percent

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*T. A. Young, Gary Steel Works Experience with Dust Control at No. 3 Sinter Plant, Blast Furnace and Steel Plant, 1057 (December 1968).

"Maintenance

Once a fabric bag collector is put into operation, the key to keeping it running properly is routine inspection and maintenance of the bags. A manometer is located at each compartment to measure the pressure drop across the bags. An excessively high or low reading indicates a fault in the cleaning system for a particular compartment. Immediate steps should be taken to correct the irregularity.

"Routine visual inspection of the bags are made each week during the sinter machine schedule down turn. They are inspected for small holes and wear, tension, and tightness of clamps at both ends. Bag tension is very important for efficient cleaning of the air, dumping of the bags, and bag life.

"Not enough tension causes excess flapping and creasing during the dumping cycle. The bag life will be greatly impaired by "super cleaning" of the bottom section. In addition, the crust built up inside the bag in the upper section may not be broken which will cause poor efficiency of the bag. If the bags are too tight, the fabric will be stressed and cause premature failure. Also, very poor cleaning will be obtained because there is not enough flexing.

"The proper tension is just enough to form several small crevices so that the bag periphery takes the shape of a star during the cleaning cycle. At Gary, we are using fiberglass bags to collect hot sinter dust, utilizing a tension of 80 lbs/sq. inch. This point is stressed because, depending on the fabric, weave, and type of dust, it could range from 30 to 120 lbs/sq. inch.

"Whenever expected life of the bags has been reached and signs of wear start to develop in several of the bags, Gary's practice is to start changing all of them one compartment at a time. This takes approximately eight weeks, with three qualified personnel working a normal work week. By following this procedure, it is not likely that all the bags will fail at the same time, making the collector inoperative.

"A facility that operates continuously is not maintenance free. There are many electrical and mechanical components to maintain in an automatic system. Of primary concern is the proper functioning of the inlet and outlet butterfly valves and timer that controls the valves. In addition, the entire system must be maintained as tight as possible by replacing seals and patching holes in ducts when necessary."

8.4b Oil-fired Boiler - Southern California Edison Company in 1957 began pilot plant studies on the control of fly-ash from an oil-fired power plant. These led to a full-scale installation in 1965 of a bag house with 1272 fiberglass downward-flow inside-filtering, collapse-cleaned bags:

Volume of air:	820,000 CFM at 258°F
Pressure drop across bags:	5.7 inches of water
Number of hoppers in collector:	12 compartments
Bags per hopper:	106
Bag size:	11.5 inches diameter, 38.75' long
Life of bags:	one year estimated
Air/cloth ratio:	5.7:1. normal - 6.5:1 with one compartment out
Deflation cleaning air/cloth ratio	3.5:1

Because of a variety of difficulties the start-up period for this equipment extended at least into the fourth year of operation. These difficulties are summarized below; although they do not represent normal routine operational or maintenance practices, they are probably typical of the problems connected with the use of dust control equipment in a new field. In this case control of oil fly ash was made especially difficult by the small particle size, and by the requirement for alkaline additive ahead of the filter for protection of the fabric. In retrospect it appears that a large part of the start-up difficulty could have been avoided by consideration of the effects of moisture on the fabric.

"Operating Experience[*]

The operating history of the filterhouse can be divided into five periods, based upon complete bag replacements or major changes to system components...

"Period 1 - January 1965 to September 1965

Initial operation was unsatisfactory. Problems were encountered with bag failures, high bag and system pressure drops, uneven gas and additive distribution and pneumatic ash removal. A portion of the bag failures resulted from mechanical conditions such as inadequate attachment at the lower tube sheet or excessive flutter in local zones of high turbulence. However, the major cause of the failures was attributed to fabric deterioration associated with wetting of the bags by moisture condensed from flue gas which leaked into the filterhouse during off-stream periods while the boiler remained in operation. To eliminate the flue gas in-leakage, an operating procedure utilizing the deflation fans and manually positioned dampers was devised to provide an air seal during off-stream periods.

As corrective measures for the uneven flow distribution and high system pressure drops, turning vanes were installed in the inlet and outlet ducts. and the flow area of the filter-house outlets was increased. A second deflation fan was added to increase the deflation flow with the expectation of improving reverse flow cleaning effectiveness...

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[*] F. A. Bagwell, L. F. Cox, and E. A. Pirsh, Design and Operating Experience with a Filterhouse Installed on an Oil Fired Boiler, JAPCA 19; 3, 149 (March, 1969)

"Period II - September 1965 to March 1966

During this interval, bag failures attributable to mechanical causes essentially were eliminated, and average bag life was much improved over that experienced in Period I. However, after about 3 months of operation, discoloration and stiffening of the fabric was noted along the deflation creases. Random bag failures commenced about a month later and, after 5 months of operation, the frequency of failures reached the point that replacement was considered necessary...After 3 months of operation, the pressure drop across the bags adjusted to 320 MW reached a value of 9.5 in. w.g. which was considerably higher than the expected value of 4.0 in. w.g.

...analyses indicated that moisture from the atmosphere had been absorbed by the cake when the filterhouse was out of service and cold. There were strong indications that the discoloration and stiffening of the fabric were associated with these outages.

...To improve operating flexibility during periods of low load operation, when moisture could be absorbed by the filter-cake, a cold air bypass was installed around the air preheater to control gas temperature to the filterhouse at low loads.

"Period III - March 1966 to September 1966

Prior to operation, a new set of filterbags made from continuous filament fiberglass fabric was installed. It was believed that these bags might have better cake release properties which would result in a lower pressure drop, but this did not prove to be the case. Instead, the measured pressure drop was more than 50 percent higher than that experienced with the bulked fiber fabrics previously used... Following only 3 weeks of operation with this set of bags, the unit was taken out of service for a 2-month period for a scheduled turbine overhaul.

...Within 3 weeks after return to service, bag failures became so numerous that the run was terminated. The premature failure of the bags was attributed primarily to fabric deterioration during the long out-of-service period on the filterhouse.

"Period IV - September 1966 to November 1967

Continued development could not be justified if improved bag life could not be obtained. Therefore, the decision was made to concentrate on bag life during this run. Operating changes to reduce pressure drop were deferred in view of the unknown effects on bag life.

...The bags selected for this operating period were of bulked fiber fiberglass fabric with a silicone-teflon finish and were identical to those that had given the best results in previous runs...

In view of the deleterious effects of filterhouse outages on bag life, continuity of operation was maintained at the expense of normal flexibility in unit loading and outage scheduling. An extensive research program including regularly scheduled collection of fabric and filtercake samples from selected locations also was conducted during this operating period. The fabric properties and the chemical composition of the filtercake were evaluated to detect fabric deterioration and abnormal changes in filtercake chemistry...

The positive effect of this emphasis on bag life is evident from the operating record which shows that the filterhouse was operated over a 7-1/2 month period during which it was in service 92 percent of the time.

...modifications to reduce maintenance and operating costs, to decrease pressure drop, to improve operating control and to further extend bag life were justified.

1. New deflation fans with more than twice the capability of the original fans were installed. Experience on the pilot and the prototype units showed that better cleaning and, hence, lower bag pressure drops were possible with higher deflation flows...

2. A new ash handling system was installed. . . . . . At the original lower deflation flows, up to 50 percent of the material removed from the bags was recirculated through the deflation system to the inlet of the filterhouse...

3. Electric heaters were installed to maintain the filterhouse at a temperature of 200°F during off-stream periods...

4. The seal air system was improved through installation of duct work, dampers and controls to permit application of seal air from the main control room...

5. A new alarm system was installed to detect plugging of additive feed lines to the individual compartments...

"Period V - November 1967 to March 15, 1968

Following completion of the alterations and the installation of a new set of bags, the filterhouse was returned to service....Alterations to the filterhouse resulted in satisfactory performance. Specific observations include...

1. The high deflation fan capacity has contributed to a lower average bag pressure drop. After 4 months of operation, the average bag pressure drop corrected to full load (320 MW) was 5.7 in. w.g. This compares with a pressure drop of 8.4 in. w.g. after a similar interval of operation in the Period IV....The deflation fans have been used to maintain a 3.5:1 flow ratio for cleaning throughout this period, but the higher deflation flow caused one problem not previously encountered. During deflation, the bags in some of the compartments collapsed completely between the first and second rings which inhibited cleaning of the remainder of the bag. The constriction was eliminated by reducing the spacing between rings in the lower portion of the bag.

2. The new ash handling system has functioned satisfactorily resulting in greatly reduced manpower requirements. During limited testing, the efficiency of the dust collectors was 88 percent which is higher than expected. This is probably the result of particle agglomeration which occurs within the filtercake.

3. With the heaters maintaining specified compartment temperatures during off-stream periods, the bag condition is much better than that in any of the previous four Periods. There has been practically no discoloration or stiffening of bag material...

4. The new automatic seal air system has worked satisfactorily on 15 separate occasions.

5. The new compartment additive feed alarm system has proved reliable..."

8.4c Copper Smelter - The Hudson Bay Mining and Smelting Company, Ltd. found that an electrostatic precipitator handling gases from a reverberatory furnace and other plant operations was not satisfactory. As an alternative, part of the gas was diverted through other cleaning equipment, and the remainder was passed first through the precipitator and then through a baghouse, with good results.

First a pilot baghouse was tried, having 26,208 ft^2 of Orlon^R, Dacron^R fabrics. Over a one year period, only one incident marred the operation: a period of low gas temperature resulted in corrosive destruction of both types of fabric. A glass baghouse also on trial in parallel continued to operate, however, demonstrating the feasibility of filtration at a temperature above the dewpoint:

Pressure across bags:	6 to 8 inches of water
Bag size:	5 inches diameter by 9.33 ft. long
Air/Cloth ratio:	2:1 to 3:1
Temperature:	225 to 450°F
Bag cleaning cycle:	Shake for 30 sec at 16 min intervals
Dust load:	1,100 lbs. per day.

"During the course of this work familiarity was obtained with details which were of critical importance to glass bag life. It was found that flexing or creasing quickly breaks the high tensile strength fibres and creates a hole in the bag. Handling should therefore be kept to a minimum both during handling and after the bags are in operation. Attrition between bags or with a metal surface soon develops a weakened area in which holes develop. Bag spacing in relation to other bags and compartment walls is therefore of concern and must be accompanied by proper tailoring. Unless the bag seam is adjusted to result in an even circumferential tension on hanging, a "banana" effect results when the bag is inflated and attrition occurs in spite of ample spacing. A deep cuff which extends above the floor nipple end of the bag and hence absorbs the flexing action imparted by the shaking mechanism in two layers of cloth was found to extend bag life in our design."[*]

From the pilot study a 205,000 SCFM collector was designed having 120 compartments each with 154 upward-flow, inside-filtering bags as sized above for a total of 221,760 ft^2. A variety of fiberglass fabrics were tested, t only two were found adequate, both 1-3 twill, staple-filled, siliconized abrics with 12.2 and 12.9 oz/yd^2 weight, and 76 and 58 CFM permeability at 5 inches of water.

In operation the fabric was cleaned by automatically reverse pressurizing and collapsing the bags for 30 seconds, and then popping them open. After an 8 hour period of this repeated cleaning, during which time the differential pressure gradually increased from 6 to 12 inches of water, the bags were mechanically shaken and the 8 hour period repeated. In one year of operation, 43 percent of the bags were replaced for reasons not detailed.

Bag spacing was stressed as being influential of bag life, however. An orthogonal pattern was developed having rows, 5 and 6 deep beside the walkway. For these 5" bags, the optimum center-to-center spacing was 6 1/4 to 7 inches.

The entire system, recovering over 35 tons of fume daily, required 80 man-hours of "operating labor" per day. The success of the system was attributed to the use of glass cloth.

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[*] D. J. Robertson, Filtration of Copper Smelter Gases at Hudson Bay Mining and Smelting Co., Ltd., Can. Min. and Met. Bull., 326 (May 1960).